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C. F. Loweth

President W. S. E., 1908.

Journal of the
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HYDRAULIC ENGINEERING AT THE UNIVERSITY OF WISCONSIN

By Daniel W. Mead, M.W.S.E.

Presented Sept. 4, 1907.

The last twenty years has witnessed a decided increase in the relative importance of the various problems of hydraulic engineering. The development of electrical generation and transmission has rendered many of the potential water powers of the country of importance and made it possible to develop and transmit to centers of population and manufacturing, hydraulic energy which previous to this generation has been of little practical value on account of the distance of such powers from a profitable market. The design and construction of such works has become an important feature among modern engineering works. The increase in population has also enhanced the values of agricultural land and has created values for lands before considered valueless. The rise in values has made it profitable to reclaim swamp and overflow areas located near or among important farming districts until the reclamation of such land has become a very important factor in modern engineering work. The spread of population to the westward has brought into the market what was formerly known as the "Great American Desert" and has not only occasioned the settlement of much of the land which has previously been considered of little or no value but settlement has pushed on even further into the arid desert and there land has been found of great agricultural value provided water can be found accessible for irrigation. Modern agricultural investigation has made manifest the value of drainage and irrigation in areas where such improvements have not been considered essential, and such improvements have demanded no inconsiderable engineering attention. The amount now annually expended both by the Government and by private interests for the reclamation of arid lands is considerable, and irrigation now occupies an important position in the work of the engineer. The deforestization of our country, and the cultivation and drainage of farm lands has produced new conditions and established new regimens in the rivers, creating flood conditions which are threatening many of the populous communities located on the flood plains of important rivers. On this account and also on account of the importance of water powers the questions of river conservation and control have also become important. Inland navigation is again attracting considerable attention and will undoubtedly become a still

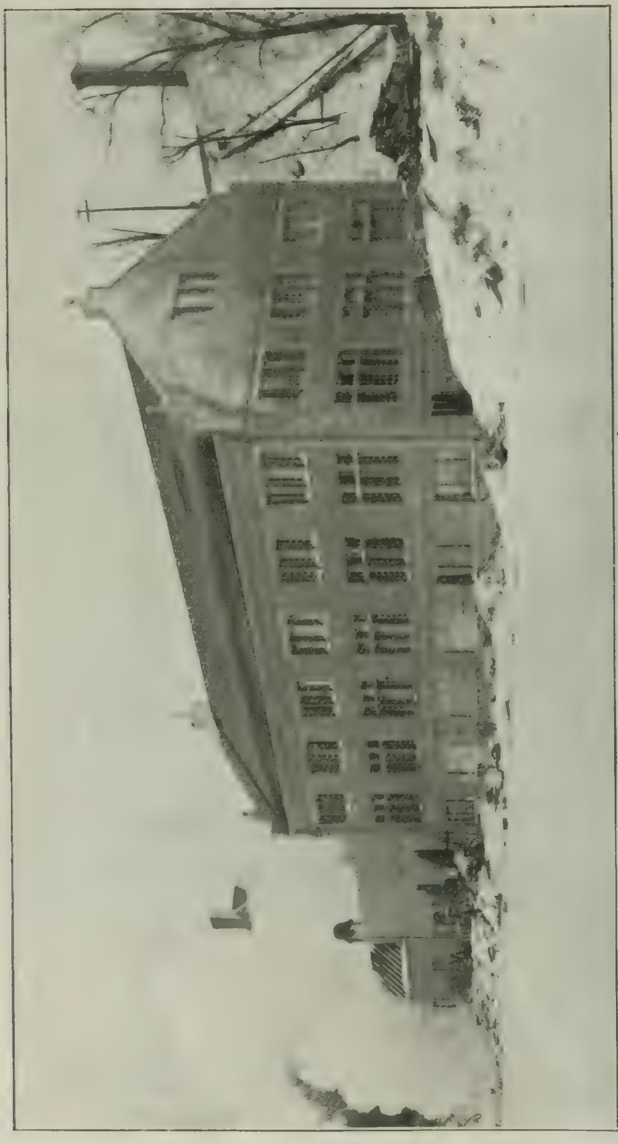
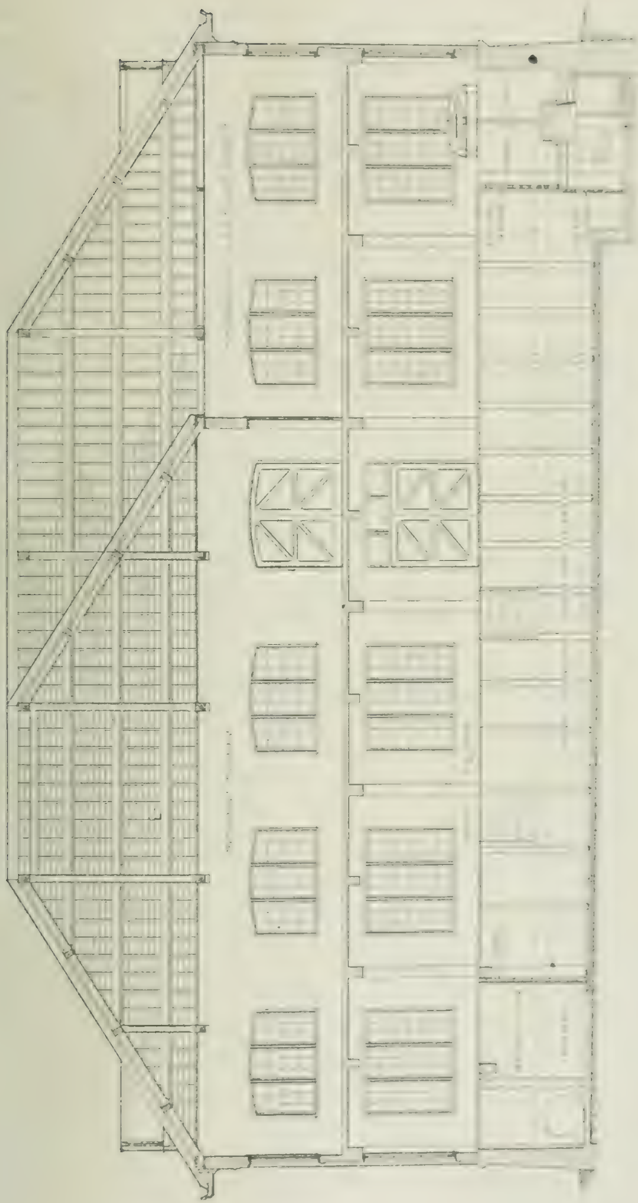


PLATE I.



more important matter as the country develops and becomes more closely populated. Modern commerce also demands greater and better harbor improvements and protection, which demand is increasing with the population of the country. The development of hydraulic machinery and its application to various purposes is rapidly gaining in importance. Machinery for the development of power, for the drainage of lands and mines, for the pumping of water for municipal and various other purposes, has become already an important industry in this country. All of these conditions have radically changed in the last fifteen or twenty years and apparently, therefore, require a considerable change in the methods and matter of technical instruction in hydraulic engineering.

Prior to the year 1904 the writer had been engaged for twenty years in active practice of his profession of civil engineering, much of the time being particularly interested and engaged in hydraulic work. He had up to that time given no particular or detailed attention to the question of technical education but had decided views as to the desirability of a considerable change in such education as applied to the line of work in which he himself was engaged. In that year he was offered and accepted the chair in hydraulic and sanitary engineering in the University of Wisconsin with the privilege of continuing his professional practice. It was understood that the writer should develop the department of hydraulic engineering on the lines of his personal ideas, which were fairly well understood by the University authorities, and that such development should be carried to the extent that the importance of the department or the demand for such development at the University of Wisconsin would warrant. It was also understood that opportunities would be afforded for research work along hydraulic lines, the importance and necessity of which the writer appreciated from his own studies, experience and investigations.

Three years have elapsed since the writer began his work at the University of Wisconsin. Many of his early ideas have undoubtedly changed somewhat and been modified by his experience in the educational field. He began this work with a fairly clear appreciation of the difficulties that confronted him. He recognized the possible errors to which an instructor who came, without previous experience, from a field of practice into educational lines would be liable, that such an instructor was liable to overestimate the real educational value of certain lines of information which might seem from his practical experience of importance and to underestimate the real educational value of much that was taught in technical institutions which might seem to him of little practical value or importance to the professional engineer. He fully realized the fact, however, that the best technical education did not, or should not, consist in a knowledge of a mass of disconnected practical details which might be absorbed by the student without knowledge of the scientific basis on which they must directly or indirectly depend. He believed also that

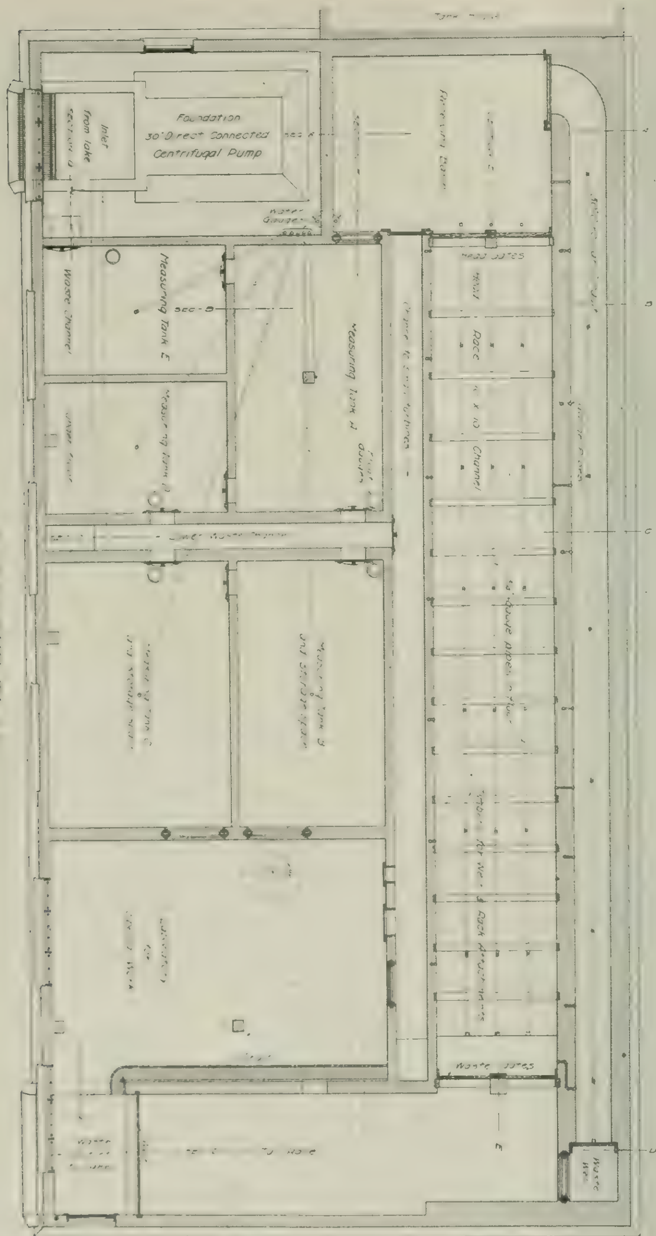
a theoretical education, having no direct bearing on the practical problems of the engineer, while it might be of value in an educational way, would better be replaced by these technical studies which had a direct or indirect relation to the actual problems of the engineer, and which, in his judgment, could be made of equal importance from the purely educational view.

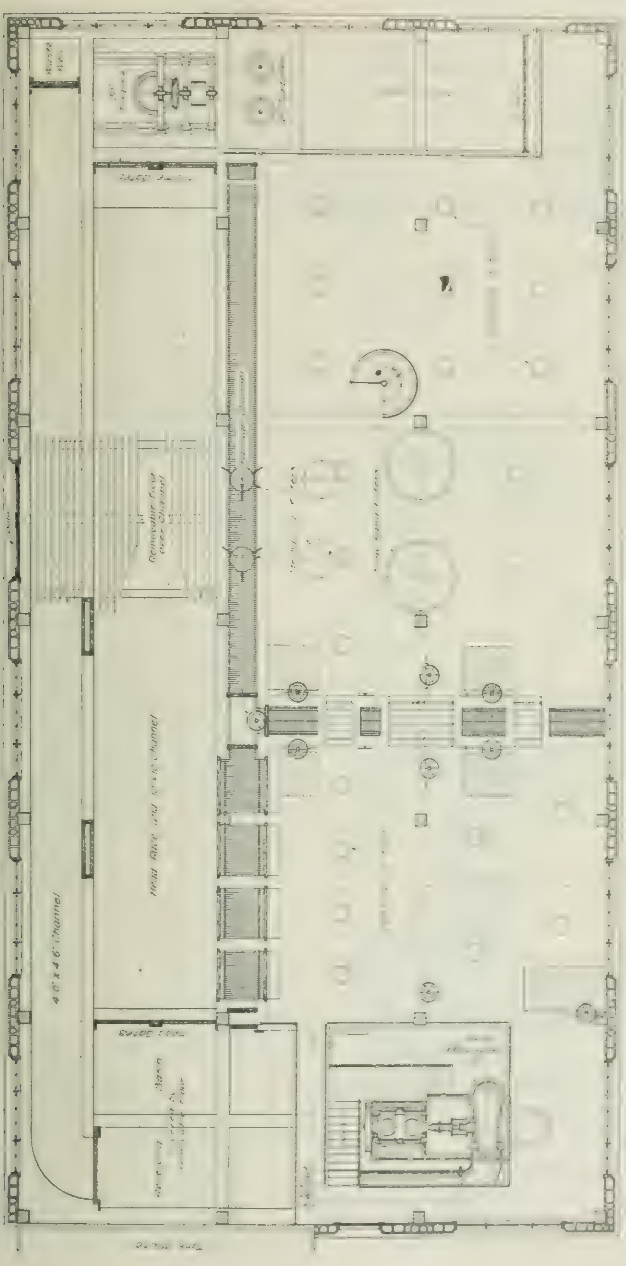
Innovations have been introduced slowly and only after careful consideration and discussion with the Dean and with other members of the engineering faculty teaching those subjects dependent directly or indirectly on the subject of hydraulics. Both the instructional method of presenting most of the subjects taught and the subjects themselves have been changed considerably from the curriculum ordinarily offered by technical schools.

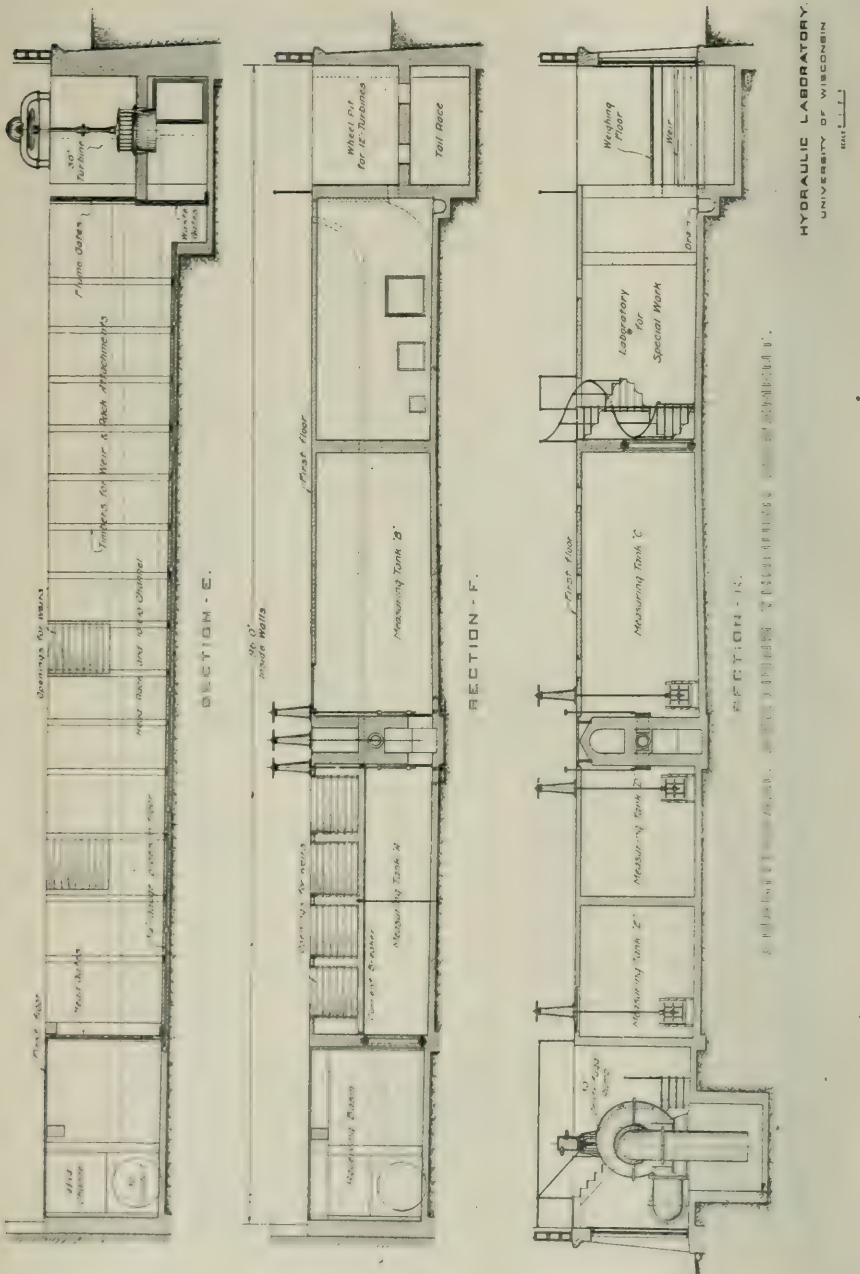
Recognizing, as he does, the possibilities of serious errors resulting from a false point of view, and the value of establishing correct principles as a foundation for the technical education of the young engineer, the writer desires to call the attention of both practicing engineers and of those engaged in instructional work in hydraulic subjects, to the changes made and the methods pursued in this department in the University of Wisconsin and to ask a fair and impartial discussion of the ideas introduced and the methods followed. That they are far from perfect, the writer is fully aware. As they now stand, they are the result of three years of careful consideration from the standpoint of the teacher and of over 25 years' practical experience in active professional work.

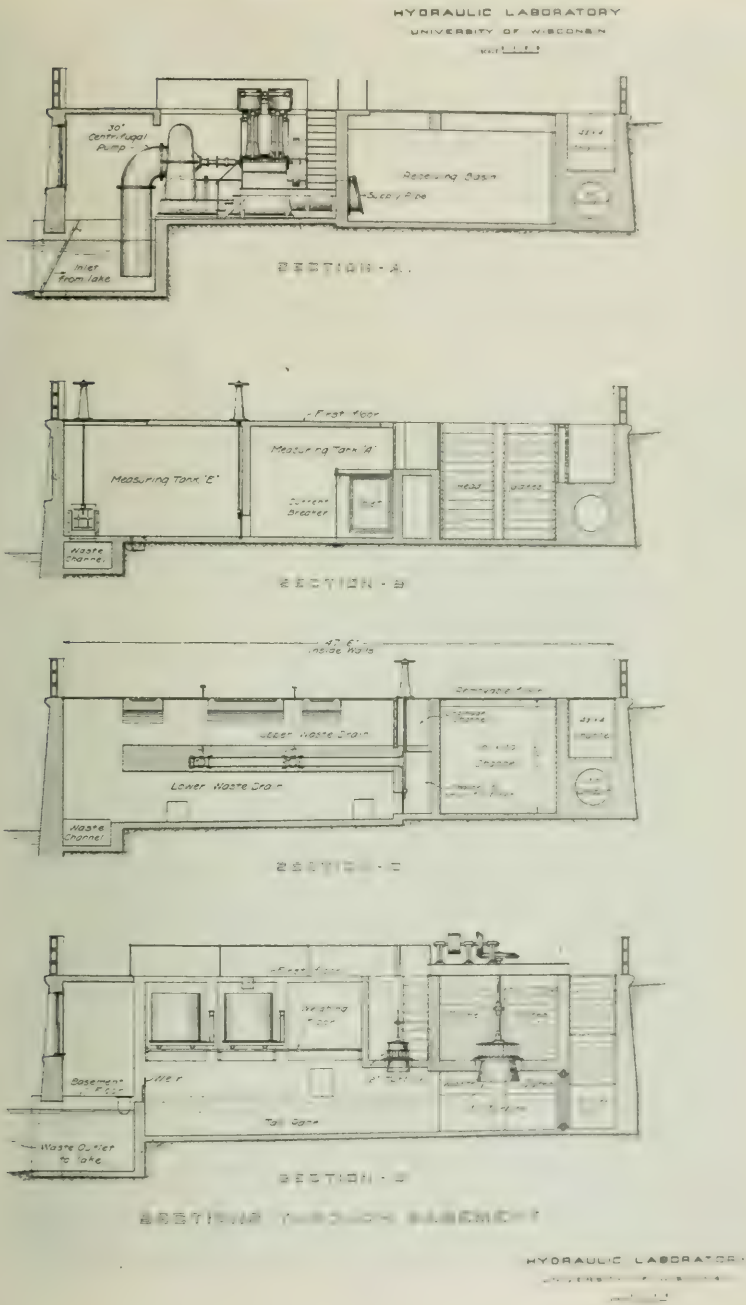
No independent department of hydraulic engineering existed at the University of Wisconsin prior to the writer's appointment to that chair. The subjects taught were divided among various departments. Theoretical hydraulics was taught by the Department of Mechanics as a part of the course in Theoretical Mechanics; Water Supply, Sewerage and Sewage Disposal were taught by a member of the faculty who also taught Structural Engineering. Hydraulic Machinery as taught included only a theoretical discussion of the hydraulic turbine and the laws of flow through its guide passages and buckets; Hydraulic Laboratory work was taught in connection with work in the Steam Laboratory. These subjects were differentiated and brought into the Department of Hydraulic and Sanitary Engineering.

Theoretical Hydraulics, as taught previous to the time mentioned, in the University of Wisconsin, and as far as the writer is informed in all other technical institutions, consisted solely of a theoretical discussion of hydraulic principles practically separate and distinct from any demonstration in the laboratory or other illustrative work. The laboratory work was a thing apart and was not carried on in connection with and as a part of the theoretical course. It has, indeed, been found impossible at the University of Wisconsin, to carry on the laboratory work parallel and in direct connection with the work of the theoretical course. This is largely due to the fact that every


Foundation
30" Direct Connected
Centrifugal Pump
Inlet from lake
Water Gauge
Head Gates
Measuring Tank E
Waste Channel
Measuring Tank H
Race
Channel
Waste Gates


Removable Floor over Channel
4.0' x 4.6' Channel


HYDRAULIC LABORATORY
UNIVERSITY OF WISCONSIN
SECTION - E.
SECTION - F.
30' Turbine
Flume Gates
Timbers for Weir & Rack Attachments
Openings for Weirs
Wheel Pit for 12' Turbines
Tail Race
First floor
Measuring Tank 'B'
96' 0" Inside Walls
Weighing Floor
Weir
Laboratory for Special Work
First floor
Measuring Tank 'C'
Measuring Tank 'D'
Measuring Tank 'E'


HYDRAULIC LABORATORY
UNIVERSITY OF WISCONSIN
30" Centrifugal Pump
Inlet from lake
SECTION-A.
First floor
Measuring Tank 'E'
Measuring Tank 'A'
Current Breaker
Waste Channel
SECTION-B
Inside Walls
Lower Waste Drain
Waste Channel
Basement Floor
Weir
Waste Outlet to lake
SECTION-D
HYDRAULIC LABORATORY

laboratory is limited both in size and equipment; that the time available for laboratory work is also limited; and that it is therefore impossible for the students each to perform the experiments at the same time they are studying the text, which would illustrate the text and make it plain and bring about a full realization of the theory discussed. This theoretical work given entirely or partially apart from any illustrative experimental or laboratory work has been very unsatisfactory in its results. Students do not, as a rule, become interested in the subjects which they with difficulty understand, and which are illustrated only by such cuts and pictures as can be made and reproduced in the text book. The students usually fail to grasp the full meaning of the theory or to appreciate its application, and to a large percentage, the course seemed of little direct value, except

PLATE 2.

fundamentally, or until they enter into active practice and begin to realize from their own actual experience the meaning and bearing of the subject.

The writer realizes that no subject can be so thoroughly well taught that it will become fully the mental property of the student until he has had the opportunity of putting it into active use in his practice in many places and at many times. He then begins to fully realize the meaning and importance of a subject from his own practical experience. It has, however, appeared to the writer that it would be possible to illustrate and demonstrate the ideas, conceptions and theories of hydraulics, which it is desired to convey to the student by class-room experiments in such a way that he could better appreciate the meaning and intent of these theories and conceptions and be more ready and able to apply them correctly to his practical work when such work comes to hand. No instructor would consider, at the present day, that physics could be well presented to the student entirely from the text book and without class-room illustrations. The fundamental ideas of physics are more completely demonstrated, illustrated and emphasized by these experiments, which often leave such an impression on the student as to remain with him through life. The writer can recall the full details of many such successful and instructive experiments in his own college days that have remained in much detail in his memory, illustrating and emphasizing principles which through them he will never forget. It therefore would seem that the same principles should be applied to the teaching of hydraulics, and with this idea in view, a lecture room is now being equipped in the hydraulic laboratory in such a manner that the

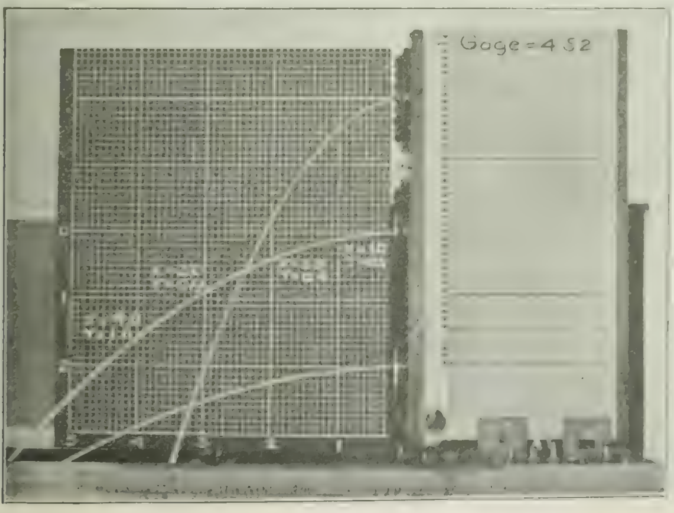


PLATE 3

fundamental ideas and principles, or, at least, the most important of them, can be demonstrated and explained to the students during the discussion of theoretical hydaulics. It is intended that the work in this line shall be carried on very much the same as in the physics lecture room. The apparatus will be arranged and ready for use, or perhaps will be already in operation, when the hour for class-work arrives. The theory will be fully demonstrated by these experiments, and, from the information gleaned from the experiment, problems will be reported and worked out in the class while the experiment is fully in mind or while it is being demonstrated or repeated. It is believed that the results of this method of instruction cannot but be a very great improvement on the previous method used. The student will not only learn from his text-book what must be expected under given conditions but will see the results of the theoretical deduction fully demonstrated. The theory and the facts in the case will be seen to accord and a knowledge of these relations will become his, for he will receive not only a mental but an optical demonstration of the same. He will not be obliged to take the statement of the teacher or author of the text book for the facts because he will see them for himself and will become himself an authority for the fact. His interest will become aroused, his attention will be attracted, and that which was before a dry and uninteresting subject will become attractive and of real interest. The result, it is believed, will be of

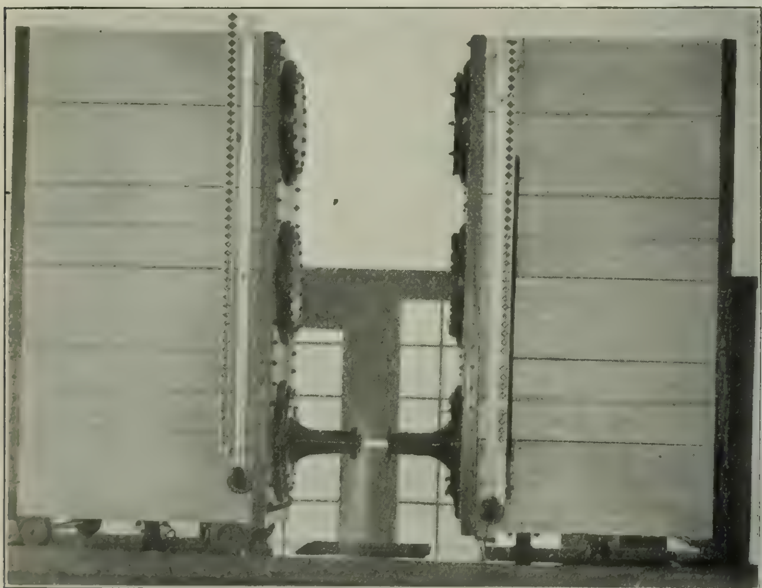


Plate 4.

importance not only in the teaching of the fundamental principles of hydraulics, but also in the laboratory work which will follow. Students will become better acquainted with the subjects and will be better prepared to undertake the determination of some of the more important facts which it is desired to emphasize by means of laboratory work.

The former laboratory at the University of Wisconsin occupied one corner of the mechanical laboratory and consisted of a very limited supply of hydraulic apparatus with a few small and elementary hydraulic machines. Within the last three years a hydraulic laboratory building has been constructed on the lake front, which affords very much better facilities than have hitherto existed for both instructional and research work.

The City of Madison is located among a group of three intermorainic lakes in Central Southern Wisconsin. The University campus lies along the borders of Lake Mendota, the largest of these lakes, and on the shores of this lake the hydraulic laboratory has been constructed immediately adjoining the University pumping station and storage tank house. A new storage tank house and pump-

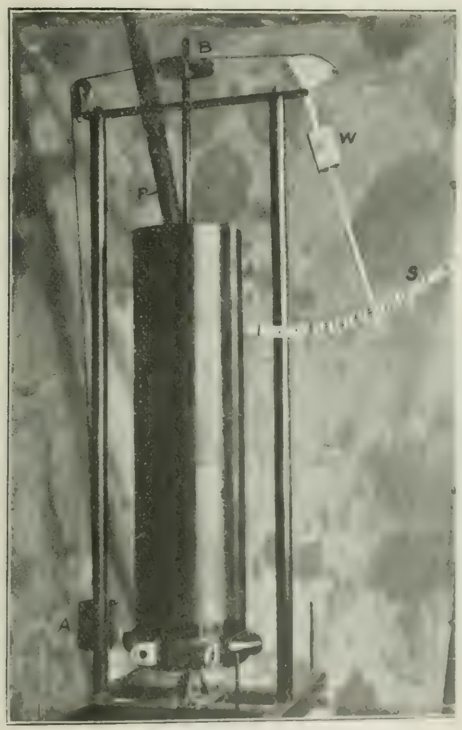


PLATE 5.

ing station forming an extensive and important part of the laboratory are to be added. In this locality an unlimited quantity of water is available for hydraulic experiments, all of which, however, must be pumped. The lake bluffs back of the pumping station and hydraulic laboratory are about fifty feet above the lake level. These bluffs afford the site for a reservoir for hydraulic experiments under moderate head, which is one of the prospective improvements but not yet constructed. The foundations, basement, walls, columns and floors of the laboratory building are constructed of plain and reinforced concrete. The walls of the building above the basement are of red brick with concrete block belting courses, and trimmings. The roof is an open truss type covered with red tile roofing. The building is forty-eight feet in width by ninety-eight in length and consists of three stories including the basement which is placed about 18 in. above the water level of the lake. In the northeast corner of this basement, and adjacent to the lake, is located a 30 in. Morris centrifugal pump, direct connected to vertical twin engines for the purpose of furnishing large quantities of water under low heads for large flow weir and water power experiments. The suction pipe of

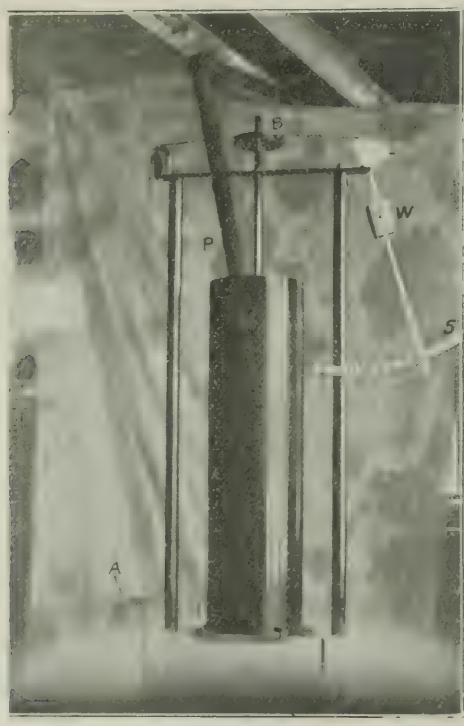


PLATE 6.

this pump is 30 in. in diameter and takes the water from a ten foot canal leading directly to the lake and of a sufficient depth to admit the flow of water when the lake is frozen over. The pump delivers the water into a receiving basin of considerable size from which it may be taken for purposes of various experiments under heads up to ten feet. Various conduits and channels are connected with this chamber as shown on the drawing. By means of these conduits and passages, investigations can be made on a scale of considerable magnitude and determinations made concerning the laws of flows in such channels and condiuts and the effect thereon of various weirs, racks, orifices and other physical features similar to those encountered in water power and other hydraulic work which may be interposed in the flow.

The receiving chamber is connected by double head gates with a channel or race way 10 ft. in width and 10 ft. in depth, which serves for large flow experiments and also as a head race leading to the larger turbine installation. In this channel flow measurements may be made with various depths of water in the channel as constructed or with varying depths in width by temporary restrictions of the cross section.

Parallel and adjoining the large channel, on the south, is a smaller channel 4 ft. in width by 4½ ft. in depth which is used in connection with various channel experiments on a smaller scale, also for the purpose of rating current meters and pitot tubes. Below this smaller channel is a 30 in. circular concrete conduit where the phenomena of flow in closed channels may be observed.

Five measuring chambers have been constructed in the basement as shown on the plan. These chambers are arranged so that they

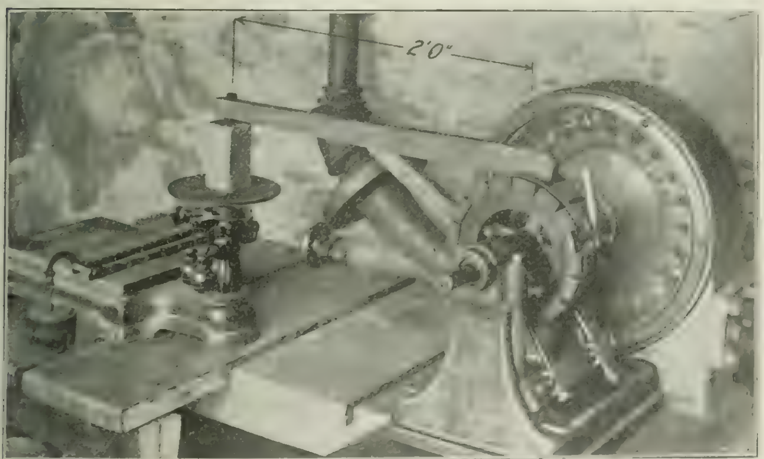
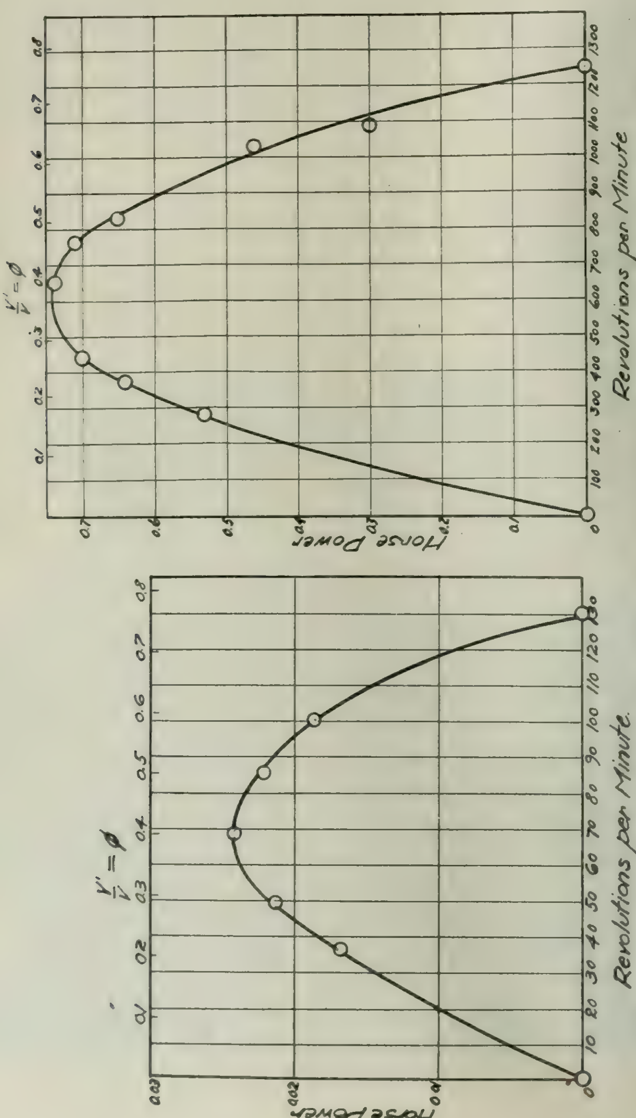


PLATE 7.

can be operated independently or together in two groups. In the double grouping of chambers, each group will hold about 5,000 cu. ft., giving a total capacity of about 10,000 cu. ft. These measuring tanks are used in experiments where measurements of a high degree of accuracy are desired of considerable quantities of water.



POWER SPEED CURVE OF A 1.0' DOBLE TANGENTIAL WHEEL

POWER SPEED CURVE OF A 1.4' REACTION TURBINE.

PLATE 8.

Their capacity is carefully calibrated between definite points by hook gauges and more approximately by glass water gauges. In the calibration of these chambers, the water is accurately weighed and allowed to flow into the tank and the elevation of surface resulting from different quantities is carefully observed. The leakage, if any, is carefully determined and allowances made therefor. In the accurate measurement of large discharges of water, the waters are allowed to flow into one of these chambers or group of chambers, as may be necessary, until it, or they, are practically filled; then by closing one valve and opening another, the discharge may be directed into another chamber or group of chambers while the first is being emptied. By this means experiments can be carried on for an unlimited period of time and the error of limited observation thus obviated. In most of the experiments, however, as conducted at the laboratory, the discharge is allowed to take place into a chamber with the discharge valves from the chamber open. When everything is in satisfactory running condition, the valve is closed and the time is observed when the surface of the water reaches a certain known elevation. The time of filling the chamber between two known points is noted and the quantity of water discharged during the known period can thus be determined within a very small fraction of one per cent.

By means of proper floor openings, these chambers can be and are used as suction pits for pump experiment purposes, when desired. One of the group of measuring chambers is so arranged that the chambers can be utilized for storage or experimental space when not desired for the purpose of measurements. They can be readily opened for such purposes or closed and utilized for volumetric measurements.

In addition to these large permanent measuring chambers, movable tanks and scales are provided for the measurements of water by weight in smaller experiments. There are also provided various smaller movable measuring tanks for smaller volumetric observation.

A number of hydraulic turbines are available for laboratory and lecture room uses. The largest of these is a 30 in. Leffel wheel which will develop about 50 h. p. under the maximum available head. This turbine is located at the west end of the 10 ft. channel from which it receives its water supply. The water after passing the wheel is discharged into a tail race 10 ft. in width in which a five foot depth of flow will be maintained. In this tail race is arranged a standard weir which has been carefully calibrated by means of smaller weirs the capacity of which was determined by volumetric measurements. This weir, in connection with a Prony brake on the wheel, will admit of the accurate determination of quantities, velocities, powers and efficiencies under various heads and conditions. Two 12 in. turbines are set in a separate wheel pit and receive their water through a separate channel, discharging, however, at the present time into the same tail race as the larger turbines. A 10 in. standard Leffel

wheel, constructed of bronze, having metal gates, and an 8 in. Platt registered gate wheel of the same material, are available for both laboratory and class room use. These wheels are of regular type and construction and enable the student to gain a clear idea of the particular wheels in question and of other similar wheels. A horizontal Girard turbine is now being constructed for the University by the Platt Iron Works and a horizontal Francis turbine will soon be purchased. Two impulse wheels and several small water motors are also available for instruction and experiment.

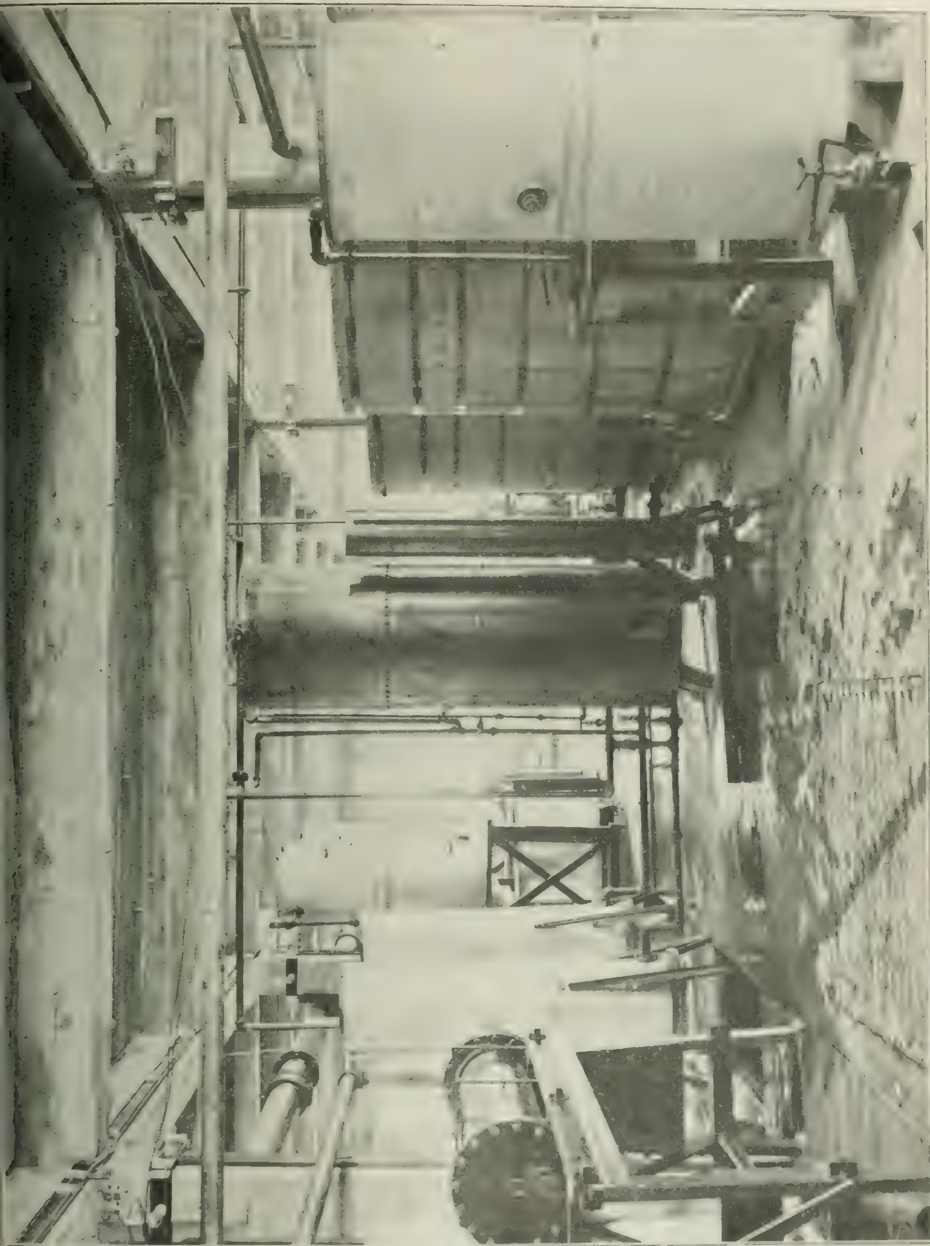
East of the hydraulic laboratory, directly connected with it and forming an integral part of the plant, are the University storage tank and pump houses. The pump house is equipped at present with one crank and fly-wheel compound condensing pumping engine and two compound direct acting duplex steam pumps. This station is soon to be reconstructed, greatly increased in size and provided with more modern machinery. The pumps deliver their water into the university mains, the excess being stored in the storage tanks under 78 pounds pressure. This pressure is maintained constant by air pressure from two air tanks, which contain air at a higher pressure (100 to 150 lbs.). These storage tanks furnish water under the higher pressures needed for many experimental purposes.

The air tanks and the compressor that supply them are also to be utilized for experimental study on the air lift and other types of pneumatic pumps.

The University is equipped with a single acting "Demming" triplex pump with cylinder 8 in. in diameter and a stroke of 8 in., also a "Rumsey" single acting triplex pump with cylinder 4 in. by 6 in., and a "Fairbanks, Morse & Co.," horizontal duplex pump with 6 in. by 8 in. cylinder. Several centrifugal pumps are available for experimental work. These consist of the 30 in. pump previously mentioned, a vertical 6 in. pump, a horizontal 6 in. pump, and a horizontal 2 in. pump. Power is available to operate the power pump from one 25 h. p. and one 50 h. p. variable speed electric motor.

The laboratory is provided with two hydraulic rams. A number 20 Rife ram which is in use for general experimental purposes is provided with a two-inch drive pipe which is arranged in six foot sections. The supply tank to the ram is adjustable and can be so arranged that it will supply water to the ram under heads varying from 18 in. to 10 ft. This variation in head and length of drive pipe together with the variation in the pressure of discharge gives a considerable range for experimental work and provisions are made for the accurate determination of the effects of such variations on efficiency and service. A smaller ram is provided capable of being worked under supply heads up to 50 pounds pressure, but with smaller quantities of water.

In connection with the hydraulic and sanitary work, there has been provided in the laboratory, four water filters. Two of these filters are slow sand filters and consist of tanks 6 ft. in diameter by 8 ft.



in height. In addition to these, one Jewell gravity filter has been purchased, and one mechanical filter containing Norwood Strainers has been presented to the University by the Norwood Engineering Company of Florence, Mass. These filters have been fully equipped for experimental work.

Apparatus has been provided for the study of the flow of water in straight and curved pipes and hose of various sizes and materials, also for the investigation of losses due to sudden enlargement and contraction and to valves and other forms of restricted passages. About 80 ft. each of 6 in. cast iron, wrought iron, spiral riveted, and wood pipes, have recently been installed, for comparative study.

A large assortment of accurate apparatus for the measurement of quantities, velocities and pressures, both in open and closed channels is available in the laboratory.

Arrangements have been made for the careful and accurate investigation of various types of instruments and of the methods used in conducting hydraulic experiments.

The regular course of instruction includes a careful selection of such typical determinations as will give the student familiarity with the application of the most important principles encountered in his theoretical work. Opportunities are offered for advanced work in practical hydraulics and hydraulic machinery and for research work on still more advanced lines.

On the upper floor of the laboratory, a lecture room 32 ft. by 48 ft. with a seating capacity of 150. This room will be provided with apparatus by means of which many simple forms of experiments can be performed before the classes in theoretical hydraulics and hydraulic machinery, thus establishing by means of actual and visible results the principles which can be emphasized and impressed on the mind of the student only in this way

Plate 3 illustrates a jet experiment by which some of the fundamental principles of hydraulics are illustrated. At the right is a tank about three feet square which is kept full of water to the desired gauge height by a supply pipe entering the tank at the bottom. Three standard orifices are placed in one side of the tank and discharge into the receiving basin upon which the tank rests. A black board ruled in feet and tenths is placed with the zero line of its abscissas on a line with the plane of the orifice and closely behind the jets passing from them. The paths of these jets are clearly outlined against the cross section lines of the blackboard.

The following illustrates two calculations based upon this experiment:

To prove Torricelli's Theorem by this experiment, i. e. that $v = \sqrt{2gh}$

$h = 4.52 - 2.00 = 2.52$

$v = 8.02\sqrt{h} = 8.02 \times 1.587 = 12.728$ ft. per sec.

Time to go 4 ft. at rate of 12.728 ft. per sec.=

$$\frac{4}{12.728}=0.3142 \text{ sec.}$$

Distance a body will fall in 0.314 sec.=

$s=\frac{1}{2}\ gt.^2=\frac{1}{2} \times 32.16\ (0.3142)^2=1.587$ ft.

Check on blackboard s=1.6 ft.

To show that the path of the jet follows a parabola with equation

$$x^2=2\ py$$
$$p=5$$

Let y=0.1, then $x^2=2\times5\times0.1=1$ and x=1 checked on blackboard.
Let y= 0.4 then $x^2=2 \times 5 \times 0.4$ and x=2 checked on blk. brd.
Let y= 0.9 then $2 \times 5 \times 0.9=9$ and x=3 checked on blk. brd.
Let y= 1.6 then $x^2=2 \times 5 \times 1.6=16$ and x=4 checked on blk. bd.

To show the conversion of energy from potential to kinetic and its reconversion to a potential form and the losses commonly entailed in such transformation, the experiment illustrated in plate 4 is introduced.

In this experiment the jet is discharged through a nozzle from the right hand tank under a head of four feet and has a velocity of about 95% of that due to the head, which may be demonstrated by a pitot tube. The actual loss in head and consequently in energy from the transformation is about 10%. The kinetic energy of the free jet after passing unconfined through a space of about six inches is reconverted into potential form by entering a gradually expanding tube attached to the tank on the left where, on account of the condition, only about 75% of the velocity energy of the jet is recovered and a loss in head of about 1.61 feet or about 44.4% results. The net result of the experiment is a total loss in the entire conversion and reconversion of 50% of the original energy.

To illustrate in the lecture room the principles of the reaction turbine, a simple form of this machine, shown in Plate 5, has been constructed. This is the form known as Barker's mill and consists of a body of 10 in. wrought iron pipe provided with a bottom and shaft and with six nozzles attached tangentially near the base. A brake pulley, B, is attached near the upper end of the shaft, and a string brake passes around the pulley, being attached to a weight, W, (with scale S indicating its amount) at one end and to a friction weight, A, at the other. Various principles of the reaction turbine are illustrated and demonstrated by the operation of this wheel. For example: to show that, with a given head, a wheel must operate practically at one certain speed in order to develop the maximum power from the wheel, water is admitted through the pipe, P, the brake cord is loosened, and the wheel begins to revolve (see Plate 6). When the head has become constant and the revolutions uniform, the revolutions per minute are determined by a revolution counter and the run away speed, or the speed at which the machine will operate without other than its own friction load, is thus shown. A load

is gradually applied to the wheel by adding weight in the scale pan, A, and the effect is measured on the scale, S.

The net added friction load is the difference between the scale reading, S, and the friction weight, A. Readings are taken with various loads and speeds. The student observes the data, calculates and plats the results in order to obtain a graphical representation of the law and impress the principle on his mind.

The same facts are also shown by experiments on a tangential or impulse wheel (See Plate 7). The following are the results of two experiments on these wheels made before a class of more than one hundred students. Each student calculated the results and platted curves showing the relation formed between power and speed (See Plate 8), thus emphasizing the fact that in both of these cases in order to obtain the maximum power the peripherial velocity of the wheel must be about 40% of the velocity due to the head.

EXPERIMENTS WITH REACTION WATER WHEELS.

Diameter of wheel.........1.4 ft.
Head of water............2.5 ft.
Diameter of brake pulley..0.5 ft.

Weight Scale S	Friction Weight A.	Net Weight On Brake.	Rev.	Calculated Power.
0.	0.	0.	130	0.
4.6	0.75	3.85	100	0.0185
6.8	1.4	5.4	85	0.0122
9.6	2.2	7.4	68	0.0242
12.0	2.9	9.1	49	0.0214
13.2	3.5	9.7	36	0.0168
14.2	4.1	10.1	0	0.

EXPERIMENTS WITH DOUBLE TANGENTIAL WHEEL.

Diameter of Wheel.......1.0 ft.
Head of water...115 ft. or 50 lbs.
Lever Arm ....2 ft.

Weight Scale S	Friction Weight A.	Net Weight On Brake.	Rev. Per. Min.	Calculated Power.
0.	0.9	0.	1250	0.
1.6	0.9	0.7	1090	0.294
2.1	0.9	1.2	1030	0.475
2.9	0.9	2.0	830	0.638
3.3	0.9	2.4	760	0.710
3.9	0.9	3.0	650	0.748
5.1	0.9	4.2	440	0.700
5.4	0.9	4.5	370	0.640
5.9	0.9	5.0	280	0.537
7.6	0.9	6.7	0	0.

Considerable attention has been and will be given in this laboratory to advanced and research work.

Experiments of considerable importance have just been completed in the channel, on the flow through a submerged orifice four feet square, the net results of which are shown on Plate 9 and the detailed results will soon appear in a university bulletin now in press. The volume of water available in this channel is about 30,000 gal, per min. or 67 cu. ft. per sec. and offers a considerable opportunity for research work with reference to apertures, weirs, racks, etc., of considerable size.

The experiments on the flow of water through submerged orifices and various forms of short conduits will be extended and it is also intended to investigate the effect of racks and other obstructions on the flow of water through this large channel.

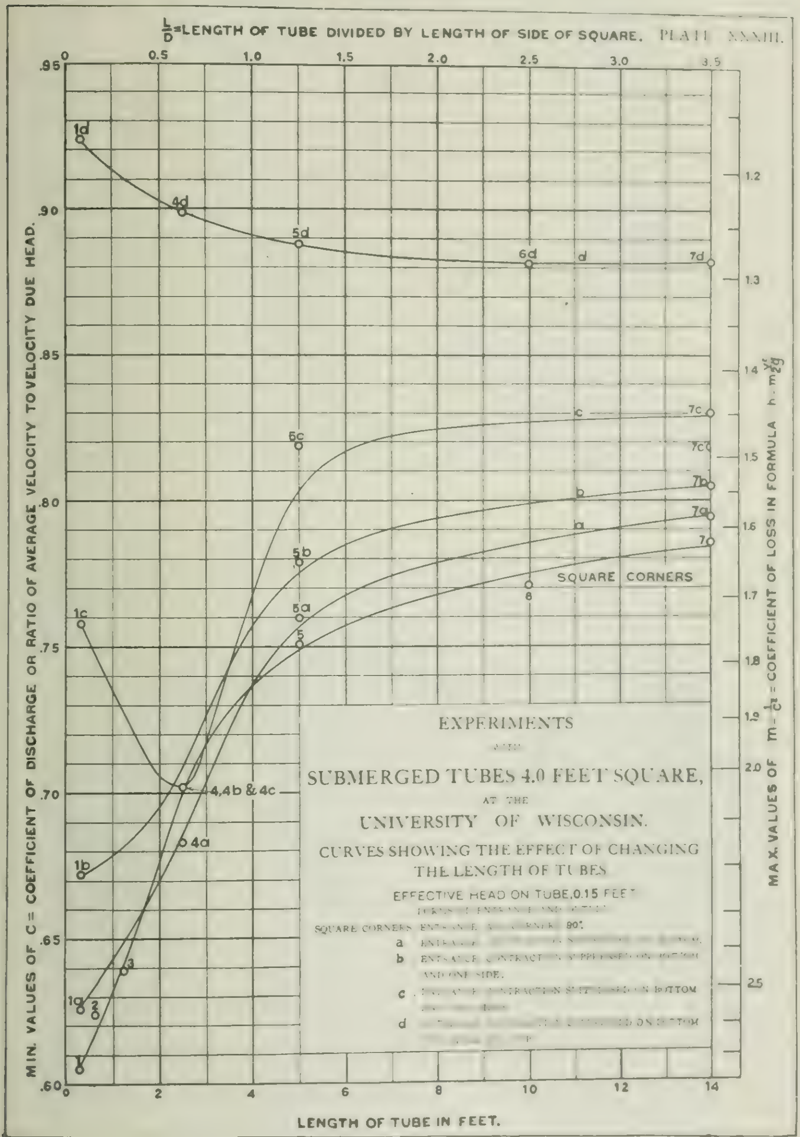


PLATE 9.

It is intended to direct advanced and thesis work into lines where further information is desirable, and to so direct and check such work by expert advice and supervision that the results obtained will be reliable and of general value. Results of interest will be further investigated, checked and extended, and as fast as the conditions seem to warrant, will be published.

Special lines of importance will be investigated by expert experimenters. One special line of experimentation which has been under way for about two years, is in relation to centrifugal pumps. For this purpose a special pump has been designed which is sufficiently flexible to admit of a wide range of change in detail. Six forms of cases have been designed, some of which can also be varied by the addition of various forms of fixed turbine blades. Twenty-four forms of closed impellers, in which the number and shape of the impeller blades vary, have been constructed. The general form of the closed impellers is shown in Plate 10, and two forms of the impeller blades are shown in Plate 11. All of these are to be increased in number and varied in design as the results of the experimental work may warrant. This experimental pump is operated by a fifty horse power variable speed electric motor, and can be run at a wide range of speeds. The motor current is determined by the most accurate forms of laboratory testing instruments, and the motor losses are determined with great care, so that the actual power reaching the pump is known with a considerable degree of accuracy. Provisions

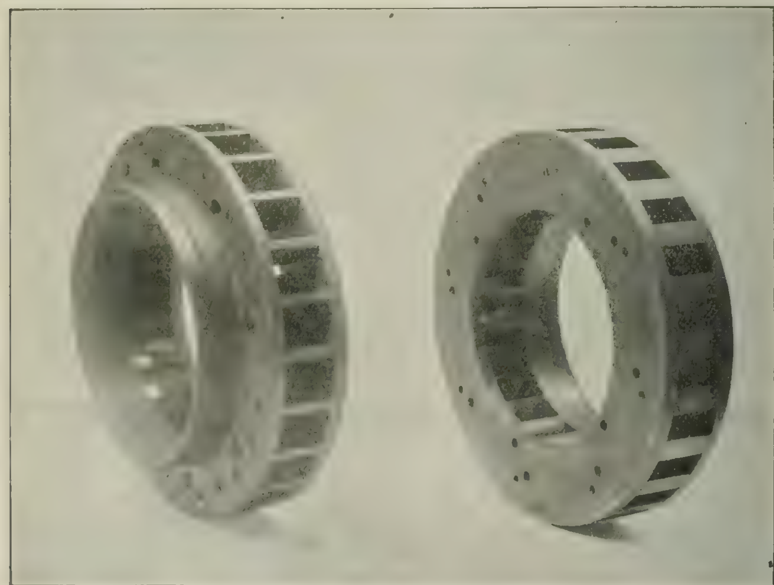
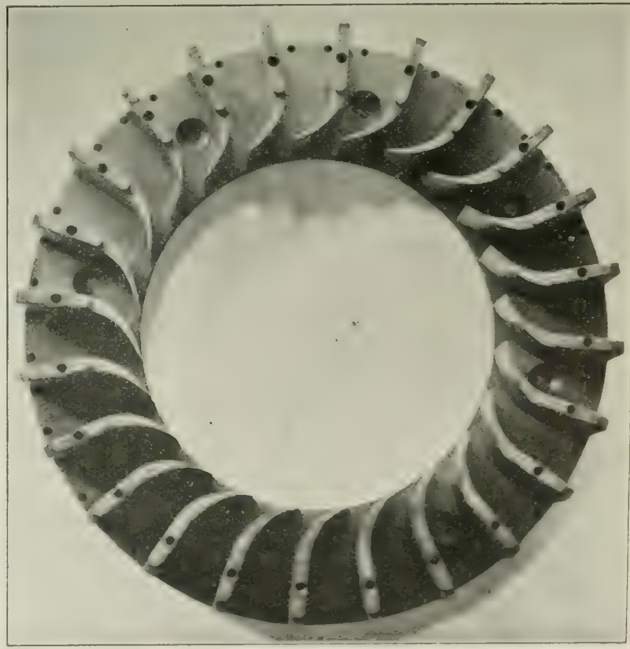


Plate 10—6-inch Vertical Centrifugal Pump.—Views Showing Form of Enclosed Radial Impellers.

12 Vanes Radial, Entrance Curved
Area of cross-section of waterway practically constant



24 Vanes Radial, Entrance Curved
Area of cross-section of waterway increasing

Views showing Forms of Impeller vanes, by removing one side of Impeller
Plate 11 6-inch Vertical Centrifugal Pump

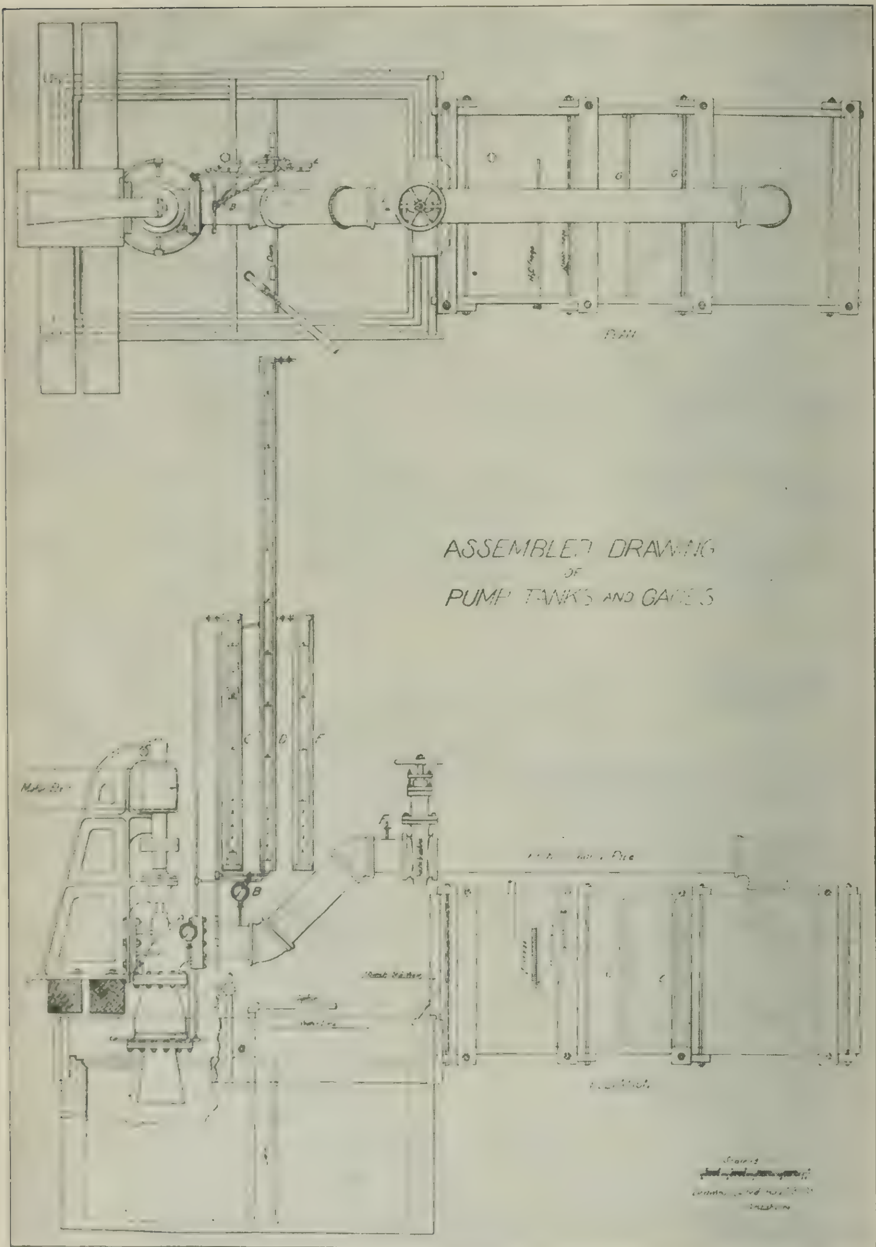


PLATE 12.

have been made for a careful study of pressures and velocities in the cases and passages of the pump, and the discharge is obtained over a carefully calibrated weir.

The object of this series of experiments is the establishment of the laws of flow in machinery of this type and the determination of the features which will result in high efficiencies and permit of the attainment of high heads. A special vertical type of centrifugal pump, intended primarily for deep well work, designed by Mr. John W. Alvord, of Chicago, has been presented to the laboratory by Mr. H. H. Porter, president of the Chicago Clearing and Transfer Company. The general form of the pump as arranged for testing is shown in Plate 12. It is also being tested in this series of experiment, which, it is expected, will also be extended to pumps of various standard designs and manufacturers. A section of this pump is shown on Plate 13 and the net comparative results of certain tests, in which the number of vanes and the shape of the water passages were varied, are shown on Plate 14. The effect of a change in the form of entrance to the six inch impeller, with water area constant, is also shown on this plate. The marked improvements in the efficiency and discharge of the 12 vaned impeller when used with a spiral pump casing, over that obtained in the pump in question, are shown on Plate 15. The detailed results of the experiments briefly outlined above are published in Bulletin No. 173 of the University of Wisconsin and can be obtained through the Librarian of the University at Madison.

While the subject of hydraulics is one that has received much attention from the earliest times yet there are many conditions that have not been sufficiently investigated and principles that have not been thoroughly established.

The research work of the hydraulic laboratory therefore is believed to be an important part of the work of the department.

There has been introduced into the curriculum of the hydraulic engineering department the subject of hydrology, not hitherto taught in the University of Wisconsin, or, as far as the writer knows, at any other institution. From the writer's practical experience in hydraulic work he believes that the most prolific source of failure in hydraulic installation, hydraulic problems, or schemes in which hydraulic problems are involved, is the lack of fundamental knowledge of many of the principles that are included under the title of hydrology. The writer has stated in another place that "hydrology, in its broadest sense, treats of the properties, law and phenomena of water; of its physical, chemical, and physiological relations, of its distribution and occurrence over the earth's surface and within the geological strata, and of its sanitary, agricultural and commercial relations." In presenting this subject to engineering students such relations as bear more specifically on the work of the engineer are discussed and considered. It is the writer's belief that a study of this subject should precede all advanced work in hydraulic engineering. At present, at

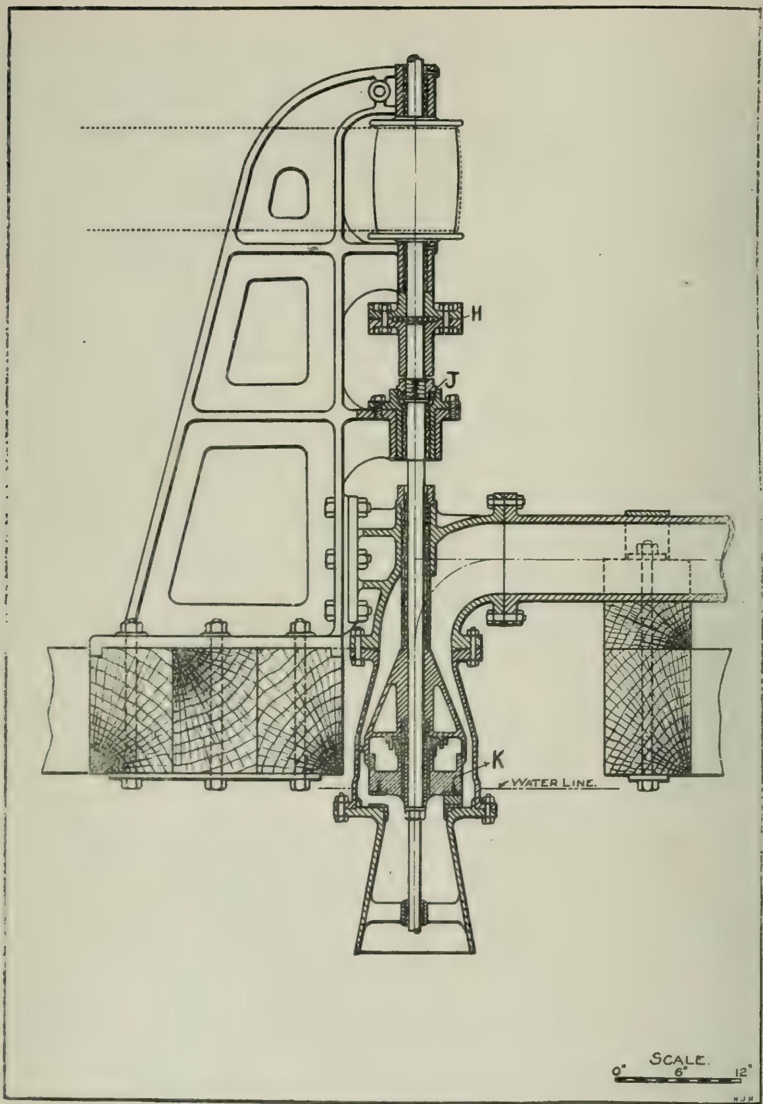
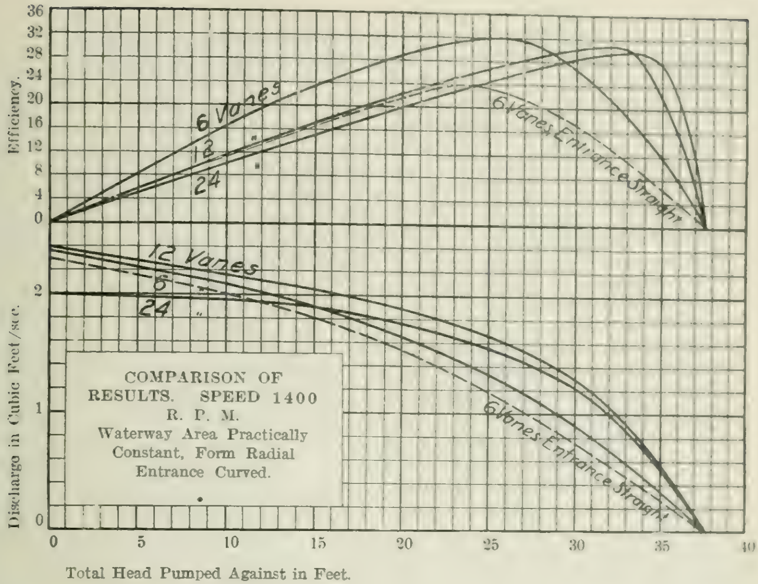


Plate 13—Test 6-inch Vertical Centrifugal Pump—Detail of Pump Frame.

the University of Wisconsin the subject is required of the students in civil engineering only, and prior to their consideration of the subject of water supply, drainage, irrigation, and of sewerage and sewage disposal. The students in mechanical and electrical engineering who are required to take up the course in water power, are not required to take hydrology as a pre-requisite to the water power study.



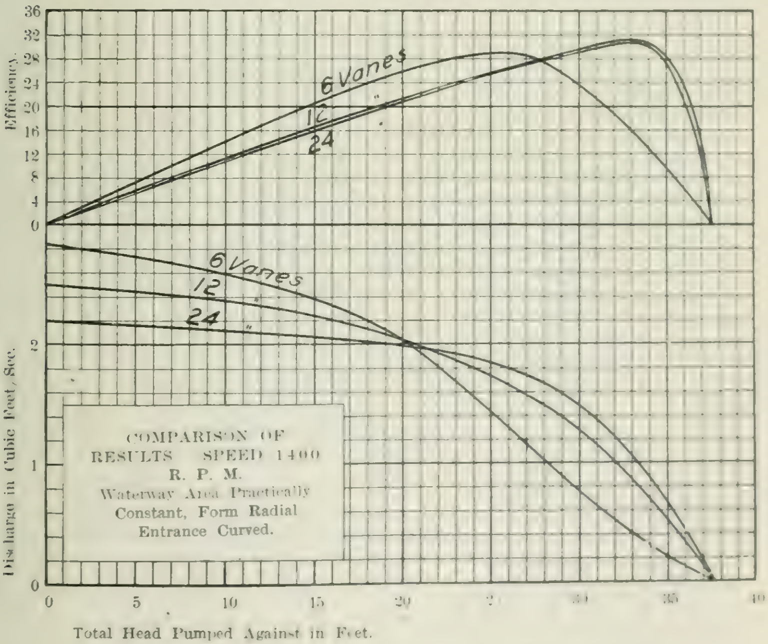


Plate 14—Test of 6-inch Vertical Centrifugal Pump.

In consequence of this fact, those elements of this subject which bear more specifically on the subject of water power are discussed in the water power class. It is the writer's belief, however, that the subject

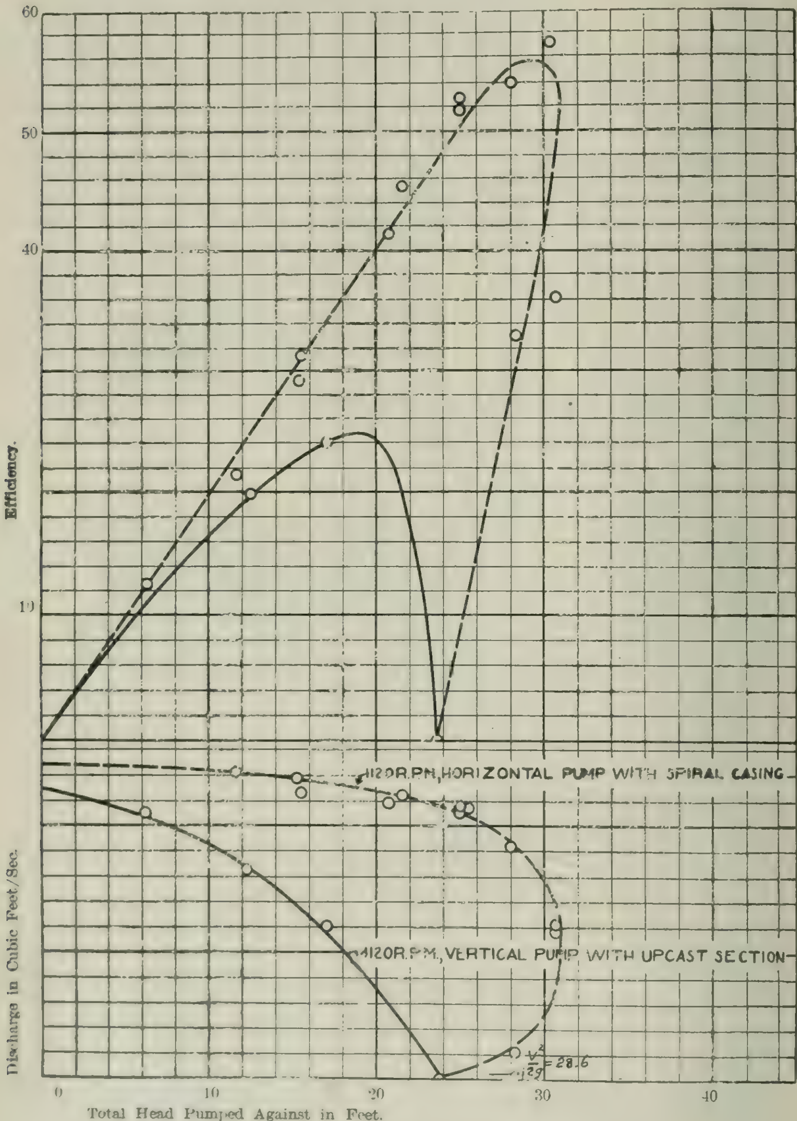


Plate 15—Curves Showing Comparative Effect on Discharge and Efficiency of Upcast Section and 6-inch Spiral Casing.
Impeller in Both Cases:—12 Vanes, Radial, Entrance Curved, Waterway Area Practically Constant.

of hydrology should be a required subject for all engineering students just as much as the subject of theoretical hydraulics.

The other subjects included at the present time in the department of hydraulic and sanitary engineering are, Public Water Supply, Drainage, Sewerage and Irrigation (considered as a single subject), Water Power, Hydraulic Machinery, and Rivers and Canals. In all of these subjects an attempt is made not only to develop the theory on which these subjects are based, but to show the application of this theory by illustration from actual practice. An attempt is made, in this way, both to make the subject an interesting one to the student and to bring home to him the fact that the principles are real, living principles which every engineer who would be sucessful must understand and be able to apply. He is made to realize as fully as possible that the theories, problems, and laws which are brought to his attention are not simply mathematical and scientific mental gymnastics for his educational benefit but are also of direct and living interest and that a full knowledge of the same is vital to his professional success. As far as possible, the structures and machines which are considered are illustrated by models and when models are not available drawings, photographs and lantern slides are used. The student is called upon to work out practical problems of such a nature that their utility is fully recognized by him and yet of such a nature that they involve the theoretical principles which must constitute the educational foundation of every successful engineer. The student is taught that a knowledge of the methods of theoretical analysis is essential for his successful consideration of a subject, but that the development of his judgment is of equal importance. He is taught that both theoretical knowledge and practical technical experience must go hand in hand and that either without the other is imperfect; and an attempt is made to have him fully realize the advantage of his educational opportunities, at the same time to fully understand that without the actual experience that is developed only by practice his theoretical education is unsatisfactory and incomplete, and can be applied only with almost certainty of serious error.

Outside of the subject of theoretical hydraulics perhaps the greatest departure that has been made from past practice among technical schools is in the instruction on the subject of hydraulic machinery. All text books on hydraulic machinery so far as the writer is aware, are written principally from the standpoint of the designer, or the man who is expected to undertake the construction of this class of machinery. That is to say the theory of the machine and the theoretical effect of modification in form and design are discussed and the practical results of its actual use are not considered. Of the students who pass through our educational institutions a very small percentage give their time and attention to the manufacture of hydraulic machinery. Almost all of them, however, will use machinery of this kind to a greater or less extent. Almost all of them, therefore, are interested in the selection of the machinery, in its in-

stallation, its operation and maintenance, and it is from this standpoint that an attempt is made to consider this subject at the University of Wisconsin. The engineer who is called upon to select and install this class of machinery for his client or employer is necessarily and particularly interested in the details of construction so far as they will affect the efficiency and operation of the machine. He may feel an interest in the details of manufacture but a knowledge of the minutia are seldom essential to his purpose. His interest is centered in the selection of the machinery which forms a part of the plant which he is called upon to design and he regards the machines in question as only a part of a perfect whole which it is his duty to create. To him a machine is a unit, which, with other units, must be selected and installed in order to form a complete and satisfactory plant. His interest in the details of the machine lies particularly in their effect on its operation, maintenance and efficiency. He is not necessarily an expert on any one class of machinery, but he must not only understand the single class of machinery in which the expert is interested but he must also be familiar with a great variety of machinery to which other experts may be giving their entire attention and concerning the minute details of which it is impossible for him to thoroughly post himself. The mental capacity of a man is not sufficient to permit him to know in detail all things; hence the necessity of the expert. Hence, also, the necessity of the man whose general knowledge is in sufficient detail to be able to compare the values of various classes of machinery and to select those classes which are of the proper type for the particular purposes of the installation which he may have in charge. The point of view of the machine designer and of the engineer of the installation have much in common and the installing engineer is, of course, all the better fitted for his work if he understand thoroughly all the details of construction of any machine which he is called upon to select and utilize, provided at the same time, his knowledge is broad enough to give him a correct conception of the relative importance of other machine units which should be considered in selecting the parts of the complete installation. He needs specific information concerning the general features of all machines with which he must be necessarily acquainted in order to intelligently and satisfactorily accomplish his purpose. It is this conception of hydraulic machinery, which the writer is endeavoring to embody in the course in Hydraulic Machinery. It must not be understood that an attempt is being made in this case to introduce a large amount of disconnected information which, while important to the practicing engineer, nevertheless does not constitute the foundation for a proper technical education, for such is not the case. In this course an attempt is made to impart the necessary theoretical basis which will allow of correct deduction in the subject considered, to furnish the fundamental basis on which the principle of the selection of machinery must depend and to develop those principles in regard to machine construction which it is not only important

but essential, for every practicing engineer who is obliged to select, install, operate or maintain various classes of machinery, to know in order that his work shall be done to advantage. In all these subjects an attempt is also made to assure a knowledge of the literature of the subject so as to make it fully available for future study and research, to impress the necessity of careful and detailed study of each particular problem by itself and to induce a recognition of the theoretical principles which must underlie the subject and which are necessary for its proper consideration and for its successful treatment. It is the intention of the department to extend the facilities of the laboratory as far as possible to practicing engineers and advanced students for study and investigation. During the summer of 1908 the laboratory will be kept open for this purpose and for the purpose of research work. The research work described in bulletin No. 173 and the experiments on the four foot orifices have been made by Mr. C. B. Stewart, M.W.S.E. The theoretical hydraulics and instructional laboratory work has been in the immediate charge of Prof. G. J. Davis, Jr., and Mr. L. F. Harza. The advanced laboratory and thesis work is supervised by Prof. Davis and the writer.

DISCUSSION.

President Abbott: This very interesting lecture which we have had the pleasure of listening to this evening has touched upon a number of topics, any one of which would have been sufficient in itself for an evening's discussion. These matters were presented, as I understand it, not for a discussion of the specific topics presented, but to show, in general, what the Engineering Department of the University of Wisconsin is undertaking—particularly the Hydraulic section.

The line of work outlined by Prof. Mead is an example of a new demand which is put upon the engineering colleges by the people The technical schools now have two distinct functions,—one is in struction and the other is investigation. In this respect the different engineering schools of the country appear to follow similar lines, although each school selects its specialty and follows that. Wisconsin we may say is making a specialty of its hydraulic laboratory; Michigan, possibly its new work in naval architecture; Purdue, its locomotive testing plant; and Illinois, reinforced concrete investigation, with its 600,000 pounds testing machine. It is fortunate that each of these schools selects something different for its specialty and develops along that line so that the work is not duplicated.

There is being built up, in the Mississippi Valley particularly, a class of technical institutions which are now thriving with rank luxuriance; their development is phenomenal and their success is equally great and well appreciated. On this account, being supported by the different states in which they are situated, their financial support from the various state legislatures is liberal, and increasingly so. These institutions as a rule have no endowments or very small ones at best, but the yearly or bi-annual appropriations which they are

receiving represents an income from an endowment equal to that of the long established and wealthy educational institutions of the country.

The result of this development is that these western Universities form a class by themselves and are rivals of each other only to the extent of stimulating each other to do their utmost to keep at the head of the procession, all working harmoniously together in the interchange of ideas (and Professors, too, when one college has a better salary to offer than another), thereby growing up side by side and developing uniformly, each taking advantage of any improvements which another works out. The result of this must inevitably be that these western technical schools will, in a very short time, take the lead of all schools of the kind in the country, and in the world.

An educational institution, when left to its own management, that is, to the management of its Professors, very soon becomes ossified or moribund. These state institutions, being dependent upon the good will of the people, are compelled to make a strong effort to keep in close touch with the times.

The paper is now open for discussion.

Mr. Andrews Allen, M.W.S.E.: It is hardly fair to call upon a bridge engineer to discuss hydraulics. The only use that he can see in water is to build bridges over or occasionally to drink.

I had the pleasure of going through the Hydraulic Laboratory of the University of Wisconsin about a year and a half ago, when the building was in an incomplete state, and was very much interested in the preparations being made for experimental work. It seems to me that the intimate connection of the Western State Universities, with the industrial development of their states, makes this experimental work of immense importance.

As our President said a moment ago, the colleges that depend for their income on the good will of the state must give full measure of results in return. The investigations and experiments are directed to the commercial needs of the state, and the results are accessible to every one. When the experiments are conducted by individuals or firms for their own commercial advantage the investigator always experiences difficulty in obtaining correct results. When the State University supplies them they are open to all, and the result is seen not only in the development of the State, whose University carries out the experiments, but in the spread of general knowledge and information.

Then, too, the intimate connection between the Professorships in the University and the engineering world at large is, to my mind, a most important one. It used to be the idea that a Professor was paid so much salary for so many hours' teaching, and if he did not teach five or six hours every day he was not earning his money. In our engineering schools, however, a new idea has been developed—namely, that the heads of the departments *must be intimately connected with the engineering world all the time.* They cannot take

their former experience and sit down and teach the boys the rest of their lives; they must keep in touch with the world and bring the results of their own professional work into the classes, and the results of class work into their profession. It works both ways, and both the commercial and the educational sides of engineering are profiting thereby.

Last year the State Legislature "investigated" the University and reported upon certain "charges" among which was the "charge" that certain professors were devoting too much time to outside work. It speaks well for the intelligence and progessive spirit of the Legislature of Wisconsin to say that the verdict was favorable in every way to the policy as outlined above.

I graduated at Madison about sixteen years ago. When I was there we had a Professor of Civil Engineering, a Professor of Mechanical Engineering, and a few instructors and assistant Professors. I must say that I got most of my engineering education after I left college. When Prof. Mead read the list of Departments with full Professors in charge of each, I could scarcely realize what great changes had come about in such a short period of time. The western engineering school has certainly come into its own.

Mr. H. W. Carter, M.W.S.E.: How many of the engineering schools in this country are there that have any hydraulic laboratory at all?

Prof. Mead: I think most of the schools have something in the way of a hydraulic laboratory, but most of the laboratories are comparatively small. Three years ago, when I began my work at the University of Wisconsin, the laboratory was in one corner of the regular testing laboratory, the space occupied being about 16 feet square. We had a small hydraulic ram, a 2 in. centrifugal pump, friction experiments were made on flow in 2 in. pipe, the largest weir was about 4 in. wide; and everything was of small proportions. To a great extent this is true of the hydraulic laboratories of many of the engineering schools. The University of Illinois has quite a large laboratory which has been constructed within the last few years. Cornell has an ideal location with an expensive long flume and with a building constructed at its lower end. The opportunities are very great, but they have not had the money, I understand, to go ahead and do very much with the laboratory, and so far, I think, the use to which it has been put has been very limited. A number of experiments were made for the engineers of the Deep Waterway Commission which were very valuable.

The opportunities at Madison are great, and we hope to show considerable developments in the future. Of course the work in every laboratory should be confined to those lines to which it is particularly adapted. Our work must be under a low head. At Cornell the opportunities for high head experiments are good. There are some Universities where there is very little opportunity for this class of work.

Mr. E. E. R. Tratman, M.W.S.E.: It seems to me that the important feature of Mr. Mead's system of instruction is in its object of showing to the student the practical application of theories and principles. It is not a difficult matter to teach principles, or for a student to comprehend them in the abstract. The difficulty comes when a problem is encountered, and it is necessary to realize what laws or principles are involved and how they are related to the problem and to each other. This is the sort of knowledge which the engineering graduate has to acquire very largely by "trial and error" after he enters practical life. But it is quite possible so to instruct him during his college career that he will be better fitted to see the relations of theory and principles to practical problems, and so be better able to use his engineering knowledge as a working tool. In engineering education, the principles are very much the same as those which the student has already encountered in his school days when learning arithmetic. This is based on simple rules of addition, subtraction, multiplication, division, etc., all of which are easily understood. But the difficulty comes when the text book or the teacher presents a problem to be worked out. Then the student has to decide for himself what rules are to be followed, and has to analyze the problem for himself to see the relation of the figures to each other and to decide which of these figures are to be added, divided, subtracted or multiplied. Some students may work at it by guesswork, or others make a more or less blundering attempt at solution, but the boy who gets the correct result will be the one who can see for himself how the several figures or items are related and how they are to be used as parts of a whole. It is the same in engineering problems. The student must know how to apply the laws which have been taught him in the schools. The laws and principles themselves are of the most importance, but the knowledge of how to use them as working tools of theory to accomplish a work of practice is probably of even greater importance. And it is this knowledge which Mr. Mead aims at giving to his students.

Mr. P. Junkersfeld, M.W.S.E.: In listening to the remarks made by Prof. Mead I was reminded of the need of accurate information on pumps. I refer particularly to high pressure rotary fire pumps, on which there seems to be a great lack of accurate information. I know of a case where a first class manufacturer furnished a six-stage pump which fully met all the specifications of the contract. He also furnished two-stage pumps which fully met the specifications of several other contracts. But the same manufacturer attempted to build a four-stage pump of similar design, and it failed absolutely to come anywhere near filing the specifications of the contract, and yet it was made by a manufacturer with a great deal of experience. The art of building pumps is not new and ought to be pretty well understood, but apparently it is not. This is simply one instance which emphasizes the fact that there is a great deal to be learned about rotary pumps, and some of Prof. Mead's investigations will probably

go a long ways toward disseminating more definite information

Mr. A. F. Owen, M.W.S.E.: To what extent do the students take up more than one branch of engineering at Madison?

Prof. Mead: There is no course in hydraulic engineering at the University. There is a course in Civil, Mechanical, Electrical, Chemical, Sanitary engineering, and General engineering. In each of these courses certain studies are required and the required studies vary with the nature of the course, but in all courses there is a certain amount of hydraulic work required. As a general thing, besides theoretical hydraulics and elementary work in the hydraulic laboratory, all students are required to take at least one additional course in hydraulic engineering, which may be water-power, hydraulic machinery, or some other line particularly adapted to the needs of the student. At the present time the students in Electrical Engineering are required to take a course in water-power engineering. Considerable work is elective, and I think the interest the students take in hydraulic work is very well illustrated by the number that enter the classes in hydraulic machinery and other elective subjects. Last year we had in the Senior class about 125 students; of these about 75 took the elective work in hydraulic machinery. The students seem much interested in the lecturers who occasionally come from outside the University—much interested in men in touch with practice—and we found in practical elective subjects that there is no difficulty in keeping the attention of the students, because they know we are discussing something practical, and going into it from the practical standpoint.

H. W. Carter, M.W.S.E. (by letter): Prof. Mead's paper makes it evident that the University of Wisconsin occupies the very front rank in its work of instruction in hydraulic engineering. There are few schools whose hydraulic equipment are at all comparable with that of Wisconsin, as described by Prof. Mead. In this connection, however, the hydraulic testing laboratory of the Polytechnic Institute at Worcester, Massachusetts, is noteworthy. On visiting the Institute last year, I found it one of the most interesting developments of that school since my time, and by the courtesy of Prof. Charles M. Allen, Prof. of Experimental Engineering there, am able to give the following facts with regard to it:

"The main Hydraulic Testing Laboratory of the Worcester Polytechnic Institute was installed in 1895 on a water privilege some twenty minutes ride from the Institute on the Worcester & Holden electric road.

"The Institute owns and controls the entire privilege including a storage pond of some 400 acres, with an available head of about 20 feet. The principal apparatus is located in a one-story building with a basement, containing altogether about 4,000 sq. ft. of floor space.

"Water is conducted to the plant through a 40-in. steel riveted pipe about 400 ft. in length between the head gate and the building. The pipe line has a gradual slope and is equipped with piezometer rings placed about 10 ft. from either end. A 36-in. Venturi meter is inserted in the pipe line just inside of the building giving a means of measuring the water before it passes through the turbine.

"An 18-in. Hercules horizontal turbine with a 12-ft. draft tube furnishing about 80 h. p. is available for various experimental purposes, such as power and efficiency tests. The turbine, after being carefully rated by an Alden absorption dynamometer mounted on its shaft, can be used as a transmission dynamometer to drive pumps and machines of all kinds to determine their efficiency.

"The turbine discharges into the weir flume in the basement. At the lower end is located a standard 10-ft. weir with end contraction. The weir flume is 60 ft. long by 16 ft. wide with a depth of 3.5 ft. below the crest of the weir. It has a smooth plank bottom and is enclosed with brick walls. There are two sets of hookguage tanks set flush with the brick walls and extending down to the bottom of the flume. The length of weir is adjustable from 16 ft. without end contractions to as small as desired with end contractions.

"The 36-in. Venturi meter above referred to has the up-stream throat and down stream piezometer rings connected with 1-in. piping to 3/4-in. glass tubes located in the tower of the building. The up-stream and throat rings are piped to the automatic recorder furnished with the meter. Piezomeer tubes and water gauges for showing the heads on the various pieces of apparatus are also located in this tower, which rises a few feet above the level of the pond.

"The Venturi meter discharges into the casing of the turbine and also into a 12-in. Union water meter. Taper blanks and rings are inserted in each line, taking the place of large valves, and are found to be very satisfactory.

"A graduated gauge showing the turbine gate opening protrudes through a stuffing box on the casing, and a mercury gauge to show pressures at various points on the draft tube is located nearby. On one end of the turbine shaft is a revolution counter manipulated by a positive clutch drive and on the other end is the Alden absorption dynamometer.

"Water under pressure is furnished the dynamometer by a 4-in. Gould hydraulic ram or by a small Dean triplex power pump driven by a 36-in. Pelton water wheel, both situated in the basement of the laboratory.

"When running power and efficiency tests on pumps, etc., requiring the entire power of the turbine, the load absorbed by the dynamometer is reduced to a minimum by attaching a draft tube to the water exhaust, thereby creating a partial vacuum in the dynamometer and thus diminishing the friction on the revolving discs. In this way the actual power absorbed by dynamometer can be reduced to 0.3 h. p. at 100 r. p. m.

"There are three kinds of turbine governors at command and these are used primarily for illustrative and experimental purposes. The Snow and the Improved Lombard, built by the Holyoke Machine Co., of Worcester, and the Replogle governor, built by the Replogle Governor Works, Akron, Ohio, make up the present installation. The unit is especially fitted for experimental work upon turbine speed regulation on account of the long penstock effect and the means of easily and quickly changing the load on the turbine from maximum to minimum, also by the effect of a fly wheel on the turbine shaft. The plant is already equipped with electricity, and arrangements have been made to install a new form of electrically controlled turbine governor.

"A four stage centrifugal pump, built by the Buffalo Forge Co., was arranged for testing in the manner described above. The discharge from the pump can either be measured in the 50,000-lb. weighing tank or by means of a standard weir in a flume situated nearby. The pump discharges into a pressure tank on which is a standard guage which gives the head pumped against. The supply to the pump is arranged so that a negative head from 30-ft. to zero can be easily obtained by throttling. The mercury guage connecting this line gives the actual head. There is also a pipe line connecting the main line which comes from the reservoir to the supply, which pipe gives a means for getting a positive pressure on the suction end.

"This pump is intended to furnish water under various heads to the 8-in. Pelton wheel situated just outside of the building on a level with the basement. The normal head from the pond ordinarily operates the Pelton wheel, and it not only furnishes sufficient power to drive a small Dean triplex power pump, but also gives a means of illustrating to the students a few fundamental principles in hydraulics. For this purpose the casing of the wheel is removed and a brake applied to the rim of the pulley on the shaft, so that the speed can be varied from zero to maximum, and in this way the best speed of the buckets is shown to be about half the velocity of the water issuing from the nozzle.

"The discharge from the Pelton wheel drops into a small flume, at the farther end of which is a standard weir with end contractions. A small Alden absorption dynamometer is placed on the Pelton wheel shaft and in this manner power and efficiency tests can easily be made.

"The low head turbine and the high head Pelton wheel furnish examples of both the Eastern and Pacific Coast types of power installations. The efficiency of both, including the power lost in transmission, are easily obtained.

"There is a set of weir flumes designed to be used in connection with calibrating the large standard weir. These flumes are 3 ft. wide, 14 ft. long, and 1 ft. below the crest of the weir and are without end contractions. The flumes are carefully calibrated by means of the large weighing tank and are then placed in parallel, all discharging into the large flume, and in this way a means is given to check the large standard weir.

"A Price current meter is used for experimental purposes in determining the flow of the stream below the plant. The quantity passing a given point in the stream is known, as it has passed over the standard weir, and in this way a good check is given on the tests made by means of the current meter.

"There is also installed in the plant a turbine flow recorder which automatically registers the amount of water going through the wheel both for a variable gate opening and for a variable head. The recorder was designed on the basis of the tests of the turbine at the Holyoke testing flume, and the results seem to check very closely with those found after its installation in this plant, although the conditions are somewhat different. For instance, this turbine was tested in Holyoke on a vertical shaft and under the head of about 16 ft. It is now installed on a horizontal shaft, with a 12-ft. draft tube and under a head of about 30 ft., and yet the discharge as computed from the Holyoke tests does not vary at half gate more than 1 per cent., and at 0.9 and full gate about 0.3 per cent.

"There are five distinct means of measuring the water passing through the plant, the pitometer in the pipe line, the Venturi meter, the turbine flow recorder which was based upon the Holyoke flume tests, the current meter situated in the weir flume, or in the stream below, and the standard weir.

"Within the next year, we expect to have installed a high speed turbine made by the S. Morgan Smith Co., of York, Pa. This is to be so placed that it can run in connection with the Hercules. This new wheel will be direct connected to an electric generator of the proper current and voltage so that we can supply electricity to the Worcester & Holden Railway, whenever we desire to do so for testing purposes. Our idea is to have a plant under actual operation furnishing a load variable and otherwise so that we can study the action of various styles of water wheel governors under all kinds of conditions. I might add that in connection with this, the Electrical Department now has a testing car which can be operated on any of the lines in this vicinity and that work can be conducted at the same time we are furnishing power to the road."

With regard to the method of instruction in vogue at Worcester, Prof. Allen writes as follows:

"I have read with interest the paper by Prof. Mead describing the course in Hydraulic Engineering given in the University of Wisconsin. I agree for the most part with his method of teaching the subject, namely: By the use

of experiment and illustration of hydraulic phenomena in the lecture room. He makes a statement that 'so far as he is informed in all other technical institutions, the theoretical discussion of hydraulic principles is practically separate and distinct from any demonstration in the laboratory or other illustrative work.' As a matter of information and interest to you, the method which he describes has been in use at Worcester for a good many years. We have in our lecture room a table especially fitted for hydraulic experiments of all kinds. For instance, we have a pipe line of various sizes with various fittings, some 20 feet long on the front portion of the table so fitted with piezometer glass tubes that the hydraulic gradient can be readily seen by the students for a variety of conditions. We also have orifice work, hydraulic ram with glass parts so that the action may be readily seen, also a small 6-in. turbine with a glass penstock and draft tube with a band brake for controlling the speed, etc. At the hydraulic laboratory, you will notice we have a large variety of apparatus all of which is of commercial size and working under practical and commercial conditions, all of which was installed with the idea not only of testing for efficiency, capacity, etc., but also for inspection and illustrative purposes with the various classes. For instance, the Pelton wheel is so arranged that the best speed can readily be seen by using the brake properly.

"It has been my privilege to teach Hydraulics both theoretical and laboratory work for the last twelve years, and as I said before, we interweave the two in such a manner as to get, in our opinion, the best results. I am allowed a certain portion of my time for outside engineering work, and a large part of it for the last few years has been along hydraulic lines. We have developed the Alden Dynamometer for use in large power testing, and I have made a large number of tests reaching as high as 4,000 h. p. per unit, making both power and efficiency tests on a large scale. I will enclose a pamphlet describing this sort of work, which I think may interest you.

"My reason for making these last few statements is to let you know that we also believe in bringing to the class room experience gained along practical lines.

"We give our students as much time as we can at the Hydraulic Testing Laboratory, also making one or two trips with them to the Holyoke Testing Flume and various water powers in Holyoke, or taking them to Lowell to the Locks and Canals."

CLOSURE.

Prof. Mead: I have been quite anxious to present this matter in such a way that it would receive some discussion and criticism from engineers who are interested in hydraulics, because I recognize that an engineer, going from actual practice into the work of an Instructor, is very apt to get the wrong perspective. It is readily realized that the standpoints are quite different. The man stepping from practice to college work is apt to see matter too much from the practical standpoint. On the other hand the man who is spending his entire time in college, on theoretically work, is apt to teach a great many things that might perhaps better remain out of the curriculum of a university. We all realize that theory is the proper foundation, but theory without practice is as bad as practice without theory. It is the use of the theory—as Mr. Tratman has said—the application or the ability to apply, which makes a man's education a help to him. The principle of all engineering matters must be the foundation upon which the practice rests, but I do not think it should stand in the way of the full knowledge of its application. It is only by the joining of the two that the best results can be obtained.

TUNNELS UNDER THE CHICAGO RIVER FOR ELECTRIC CABLES

By George B. Springer, M.W.S.E.

Presented December 4th, 1907.

The transmission of Electrical Energy from the several power plants of the Commonwealth Edison Company to the various substations has made necessary the construction of a number of tunnels under the Chicago River for cable conduits and it is the purpose of this paper to describe the methods of construction and some of the interesting features pertaining to them.

Up to the present time there have been constructed six tunnels; the first one, the old Harrison street tunnel, was built in 1893. This tunnel was not built deep enough, as was shown afterward when the contractor for the Union Loop power house which was built close to the east shaft of the tunnel drove a foundation pile through the roof of the tunnel. The damage, however, was not serious, as the material above the tunnel was good hard clay, and only a small quantity came through with the pile. Repairs were made by cutting off the 18 inches of the pile which projected into the tunnel and then bricking up the opening.

After the Harrison Street tunnel was built, several armoured submarine cables were installed at various points in the bed of the river. These cables were fairly satisfactory, although we have had several cases, where a dredging machine has picked up the cable, causing some inconvenience but no serious damage.

When it is necessary to install a number of cables across the river at any point, the natural question is as to the most economical method. The distance between building lines is too small to permit of sufficient space between the cables, and a short circuit or fire on one would affect adjoining cables, as the water would not afford protection from the current. Where sixteen cables or less are to be installed it can be done more cheaply by the submarine method. More than sixteen cables can be installed more cheaply in a tunnel.

The following table gives the principal data of the Company's tunnels at this time:

- DATA ON TUNNELS -

LOCATION	YEAR	HEIGHT INSIDE	WIDTH	* DEPTH	** LENGTH	TIME BUILDING	MATERIAL
HARRISON ST.	1893	6'-6"	6'-0"	50'-0"	300'-5"	8 MOS.	BLUE CLAY
WASHINGTON ST.	1903	6'-6"	6'-0"	72'-6"	479'-0"	4 MOS	BLUE CLAY & HARD PAN
INDIANA ST.	1903	6'-6"	5'-6"	72'-8"	297'-5"	3 MOS	BLUE CLAY
QUARRY ST.	1904	6'-6"	6'-0"	68'-7"	293'-1"	7½ MOS	ROCK
22ND ST.	1905	6'-6"	6'-0"	57'-11"	446'-6"	4½ MOS	BLUE CLAY & WET SAND
CLYBOURN PL.	1907	6'-6"	6'-0"	43'-2"	334'-10"	3 MOS	BLUE CLAY & DRY SAND

* FLOOR OF TUNNEL BELOW DATUM

** CENTER TO CENTER OF SHAFTS

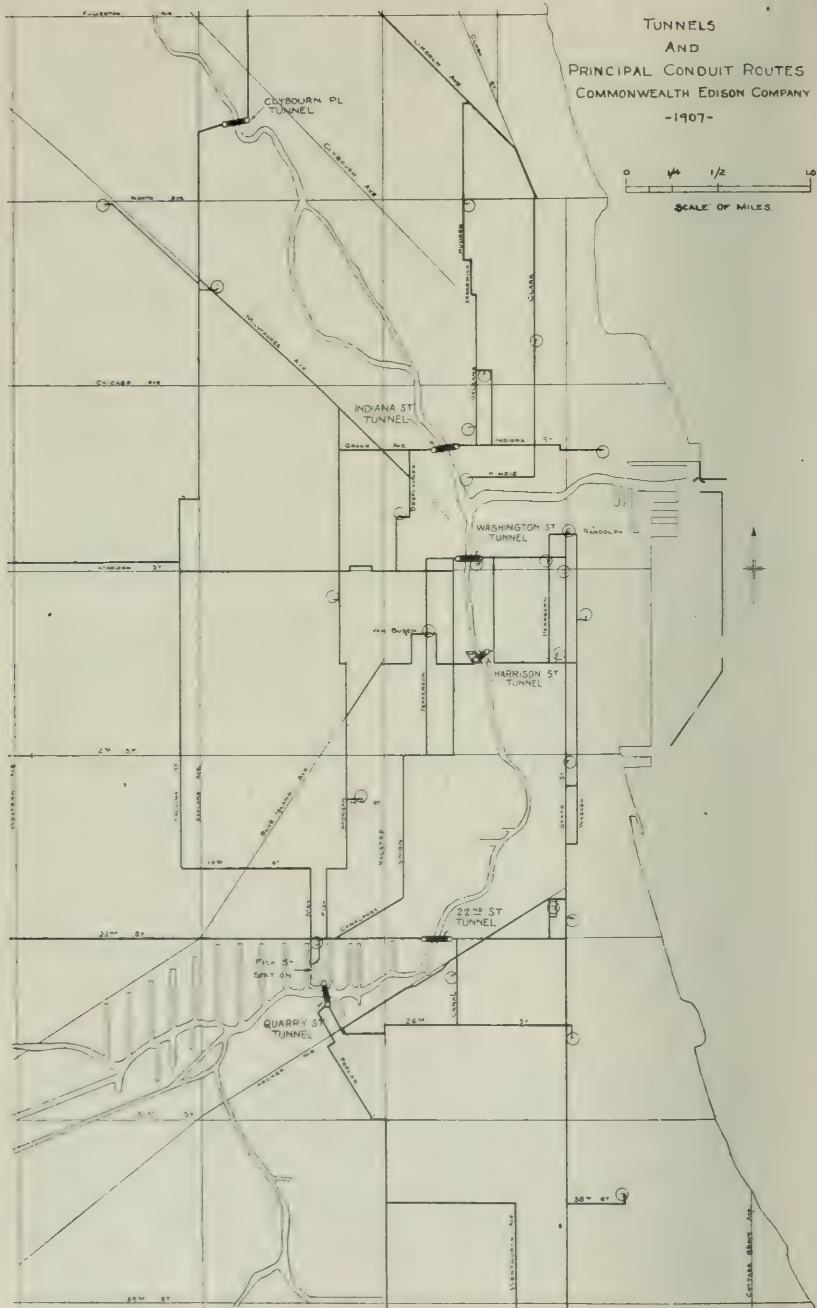


Fig. 1. Location of Tunnels.

It has, therefore, been found advisable to build five tunnels since 1903. A general map of the city, Fig. 1, shows their location and the principal conduit lines connecting the stations and substations. All of these tunnels were built of concrete while the Harrison Street tunnel was built of brick.

The cost of the tunnels varies from $13.00 to $24.00 per lineal foot, for the clay and $48.00 per foot for the rock tunnel. The cost of the shafts varies from $33.00 to $56.00 per foot, for the clay tunnels, and $64.00 per foot for the rock tunnel.

The general description of the clay tunnels will be given followed by that of the rock tunnel. In selecting locations for shafts and tunnel, the location of existing tunnels of the city or other corporations, and information regarding all other existing structures, is obtained at the City Hall and is incorporated in the preliminary plans. A permit for borings is secured from the Street Department of the City, and at least one boring is made as near as may be in the center of each of the proposed shafts.

A permit from the Commissioner of Public Works is obtained and plans filed in the City Hall having the approval of the City Engineer. An inspector representing the city is sent on the work and remains until it is finished. He makes a daily report of the progress of the work to the City Engineer. A permit from the War Department is obtained and monthly reports are sent to the Chicago office of the United States Engineers.

In looking for existing information regarding borings for artesian wells near Clybourn Place, we found that the Henning Pickle Co. had struck rock at 93 feet below datum in drilling for a well at Wabansia Ave. and McHenry street, about one half mile south of Clybourn Place; the Loesser Can Factory had found rock at a depth of 90 feet at Elston Ave. and Webster St., about one half mile north of Clybourn Place. The Illinois Steel Company whose plant is about 1,000 feet south of Clybourn Place claim to have found rock at 105 feet. As the first two borings were about the same we expected to find rock at about 90 feet, but at a depth of 70 feet, so much water was encountered with the sand that we could not go deeper without an outside casing. We, therefore, stopped the borings at this point. In Fig. 2 the borings of the tunnel are shown with the preliminary plan.

In general, if a stratum of clay is found at the proper depth, sufficient in height to permit the tunnel to be built, the result is generally a dry tunnel. Where gravel and sand strata are encountered much trouble from water results. If sufficient hard ground is not found between the bed of the river and rock the tunnel must then be built in rock. In order to avoid foundation piles, a depth of 50 or 55 ft. to the top of the tunnel is always desirable at sites where a new bridge is to be built.

After deciding as far as possible upon the location and depth of the tunnel, preliminary plans and specifications are drawn up, the con-

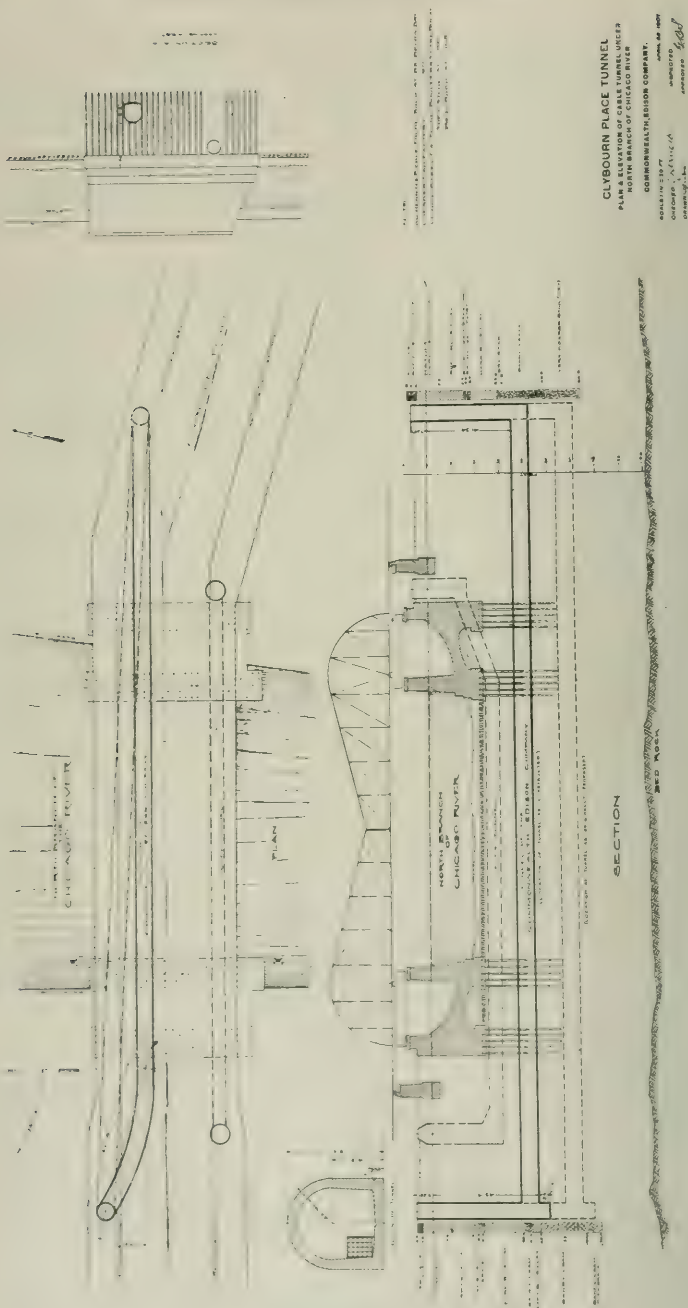


Fig. 2. Clybourn Place Tunnel.

tract is let, and the contractor erects his derrick and begins excavation of one of the shafts, usually the one which is to be the deeper, in order to drain the water from the drift. Fig. 3 shows the derrick at Washington Street.

Fig. 3. Washington St. E. Shaft, Derrick.

In good clay, the digging of the shaft is carried on by the use of iron rings ¾ in. by 3 in., back of which pine lagging, 2 in. by 6 in. by 4 ft. long is placed. The rings are securely bolted where the two halves join. In Fig. 4, a shaft is shown excavated to a depth of about 45 ft. below datum. The progress in excavating the shaft is from 10 to 20 ft. per day according to the hardness of the digging. When the shaft is excavated to the proper depth, an inside drum is placed at the bottom of such diameter as to leave an annular space of 15 in. for the concrete. The concrete is filled in in layers of 8 in. to 1 ft. and then thoroughly tamped. Other drums 4 ft. in height are added as the concreting progresses, until the top is reached. Gen-

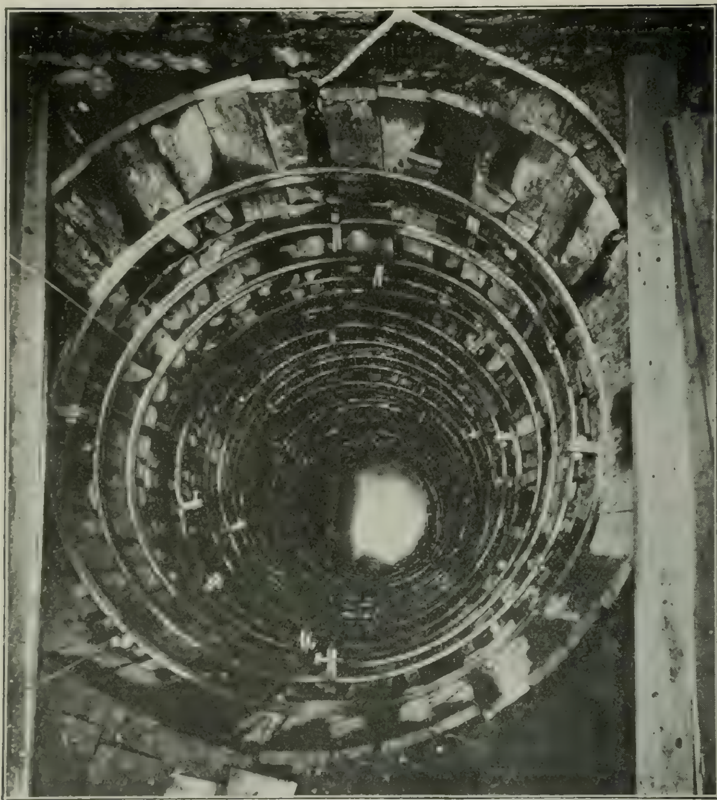


Fig. 4. Clybourn Place, Shaft and Excavation.

erally the lagging and rings are removed as the drums are placed. The concreting in shafts is done at the rate of about 20 ft. to 30 ft. per day of 24 hours. Boxes are imbedded in the concrete at intervals for the angle irons used to support the conduit and also for the ladder straps. Figs. 5 and 6 show the shafts concreted before and after the removal of the drums, which are allowed to remain three or four days.

In Fig. 7 is shown a shaft in which an elevator is used instead of buckets. This method is more advantageous as the car of clay can be shoved on to the elevator during excavation and hoisted. The concrete can be mixed at any convenient place and transferred to the elevator and lowered in cars. Angle irons for supporting the conduit 3 in. by 3 in. by 3/8 in., galvanized, are built into the concrete. A galvanized iron ladder is also built in both shafts, and secured by straps securely imbedded in the concrete. The plastering used on shafts and tunnel is composed of one part cement and one part of powdered stone or fine sand. The mortar is applied to the thickness of about ½ in., and in leaky spots soda ash and plaster of Paris are used with fair success.

The tunnel is generally begun when the first shaft has been sunk deep enough. Where the ground is good stiff clay or dry sand and clay, the material holds up sufficiently well to enable 12 ft. to 16 ft. to be excavated before concreting. This can be dug in two shifts of eight hours and concreted on the third shift. In case large boulders or hard pan are struck blasting is resorted to in order to loosen up the mass for easier excavation.

The alignment of the tunnel is obtained by dropping a fine line on each side of the shaft on the center line of the tunnel. A transit is set up in the tunnel some distance from the shaft and set on line of the two lines in the shaft. By reversing, points are set ahead as needed. Where there are obstacles on the center line on the surface of the street, offsets are taken from the true center line. When angles have to be made, the same are measured on the surface and laid off in the tunnel at the proper distances from the center of the shaft. In Fig. 8 is shown the excavation in Clybourn Place tunnel where it strikes the west shaft which had to be concreted several weeks before the tunnel was built. This will be referred to later.

The forms for concreting the tunnel are either wood or steel; 2 in. by 6 in. lagging is placed around the forms as the concreting is

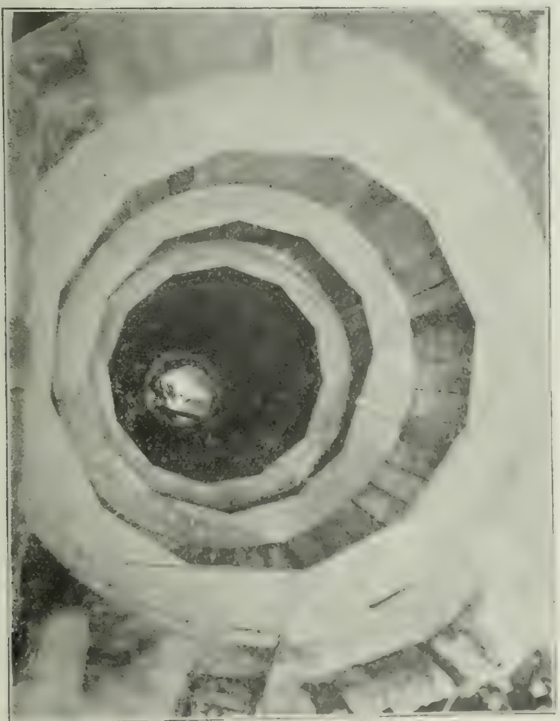


Fig. 5. Forms in Clybourn Place Shaft

done. The forms are set 4 ft. center to center. The concrete is generally placed in six inch layers, or the width of a piece of lagging; and as each layer of concrete is placed and tamped, another piece of lagging is added until the top or key is reached, and then the concrete is thoroughly tamped from the end. In Fig. 9 is shown the tunnel concreted, and with parts of the forms and lagging still in place.

Fig. 6. Clybourn Place, E. Shaft, Concreted.

This section of the tunnel was on a curve. Steel forms are used in some cases, this being an advantage as it gives more room for work. Fig. 10 shows a section of the tunnel on the curve completed, with four ducts installed; the duct nearest the wall containing a 20,000 volt line to Evanston, installed before the tunnel was completed. On completion a final survey is made of the location and depth of the tunnel and shafts and records are filed in the office.

There were several interesting features in connection with the clay tunnels which it might be well to mention before describing the rock tunnel at Quarry Street.

In the east shaft of Washington Street tunnel, a stratum of quick sand was reached at about 80 ft. below datum, which was about 15

Fig. 7. Elevator in Shaft—22nd St. Tunnel.

ft. thick. We had considerable difficulty getting through this quick sand, but by using an inner caisson built of timber and loaded with concrete and rails as the sinking took place, rock was reached at about 96 ft. below datum. The lower 20 ft. of the shaft was then filled with concrete and the tunnel drifted, at about 72 ft. below datum. A peculiar incident occurred in this tunnel about a year ago. The tunnel always very dry since completion, became filled one night with water, coming from a fire in the vicinity, flowing into a manhole and down the west shaft. The pump was started but could not take care of the volume of water which rose nearly to the top of the shafts. While rigging up for another pump it was noticed that the water had begun to recede, and at the end of two days had all disappeared. Where this water went, is a matter of speculation. The excavation for the tunnel was through hard pan and boulders as well as clay, and considerable blasting was done to loosen up the material.

Some difficulty was experienced at 22nd Street tunnel, which was built in good clay, with the exception of about 50 or 75 ft. near the west shaft, where a pocket of quick sand on the arch of the tunnel was encountered. There was no indication of bad material at the shafts, good clay showing down to about 80 ft. below datum. Special precautions were taken to make the concrete rich at this point, and the tunnel upon completion leaked only slightly. Several months after the tunnel was finished, however, it completely filled one night. Our electric pump which had been handling the water easily up to

this time, could not keep ahead of it. Therefore, the pump was taken out, allowing the shafts to fill to river level, remaining in that condition for about two or three weeks.

It was then decided to make an attempt to pump the tunnel out. This was done by pumping down about 15 ft. at a time and lowering the pump until the tunnel was reached, when the progress was necessarily slower. In about a week, however, the tunnel was emptied and an investigation made. About ten or twelve leaks varying in size from a pinhead to ½ in. in diameter were found in the arch on the north side of the tunnel. The concrete was investigated and found to be sound and compact. Considerable jetting of sawdust on the outside was then done and the pump kept going meanwhile. Gradually the leaks slowed up, and after several weeks of treatment, the tunnel was practically in as good condition as when completed. The smaller holes were cemented up, and one or two larger ones plugged, so that it required less than one hour pumping per day to keep it dry.

As to the cause of the sudden filling of the tunnel it seems reasonable to suppose that the Sanitary District in building a concrete caisson foundation 12 ft. in diameter which was sunk to rock immediately adjacent to our tunnel at the point where the trouble developed,

Fig. 8. Clybourn Place Tunnel, Excavation in blue clay.

by opening up the clay and hard pan admitted river pressure; the water filling the voids left by the removal of the quick sand on top of the tunnel, found its way through the most pervious parts in the concrete. It is also probable that during the process of pumping out the tunnel, the pressure from the outside carried considerable quantities of material into the interstices of the concrete, and that this gradual filling up and settlement of the material on top of the tunnel accounts in a large measure for the stoppage of the leaks.

Fig. 9. Clybourn Place Tunnel—Concreted.

A longitudinal section of the rock tunnel at Quarry Street is shown in Fig. 11 in which it will be seen that there is only 14 ft. from the bottom of the river to bed rock. Fig. 12 shows the derrick used, which is of a different style from the derricks used in clay excavation A sliding block can be adjusted over any point of the shaft, and when hauled up, dumps the material at the end of the derrick.

The north shaft of this tunnel was started first and, at a depth of about 30 ft. below datum, a stratum of gravel about 3 ft. thick was encountered, through which a considerable volume of water flowed into the shaft.

The difficulties encountered in keeping this shaft pumped out and the method adopted for carrying on the work are shown in the following extract from my daily report of May 12th, 1904:

> "Another boiler and pump were installed yesterday at the north shaft to pump out water, which was about 32 ft. deep. The intention now is to pump out the north shaft and blast out the rock for about 10 ft., then concrete the shaft to the top and abandon it temporarily, then sink the south shaft to the required depth, drift the tunnel across the river to the north shaft and blast up the bottom of the same, and concrete connection and tunnel. This arrangement was agreed upon with the contractor yesterday."

This programme was to enable us to build the tunnel and south shaft without the expense of keeping the north shaft pumped out during construction, and proved to be the best method of doing the work. The excavation of the south shaft was carried on by driving Wakefield sheeting and using ordinary timbering of 12 in. by 14 in. size. Deeper down, 8 in. by 8 in. braces were put in as the timbers were inclined to buckle. Figs. 13 and 14 show this construction; the latter view below the timbering shows the rock cut of this shaft, rock being reached at 48 ft. below datum. The ordinary method of using iron rings was first tried, but as the material was swelling clay, the rings became distorted to an elliptical shape, and it was found necessary to timber the shafts as shown.

Fig. 10. Clybourn Place Tunnel—Completed.

The south shaft is shown in the next view, Fig. 15, looking upward, plastered, with angle irons and ladder in place, and 35 tile ducts installed. The cable hanging in one side of the shaft is a 9,000 volt transmission line which was put into temporary operation before the conduit was installed. The 35 tile ducts are sufficient to last a num-

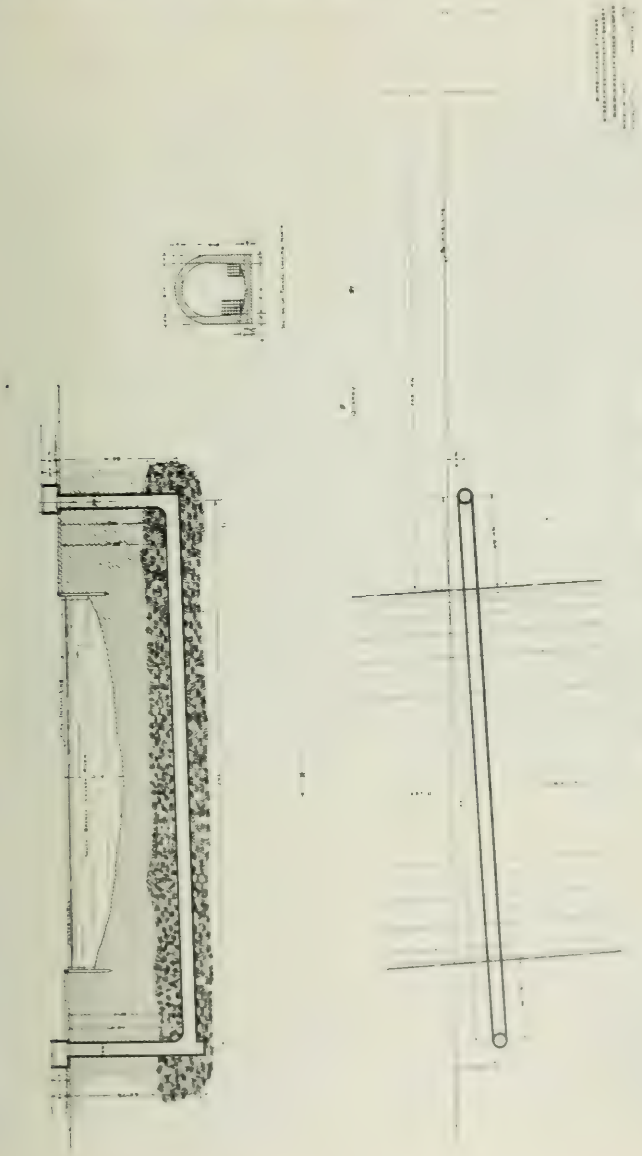


Fig. 11. Quarry St. Tunnel, in Rock.

ber of years, although on account of new cable arrangements the other side of the shafts have been recently filled. The progress made in excavating the shafts was from 10 to 20 ft per day in the softer material, and from 3 to 5 ft. in the rock. Concreting progressed at the rate of 8 to 20 ft. per day, according to the difficulties encountered. As a rule a shaft was concreted in from two to three days.

In Fig. 16 is shown the tiling around the various cables in the manhole. These manholes are usually about 14 ft. square and 8 to 10 ft. deep, and are drained to the city sewers or to the river.

Fig. 12. Derrick at Quarry St. Tunnel Shaft.

The blasting of the rock was carried on by the ordinary methods. Rand rock drills with compressed air, were used for drilling the holes, about 18 sticks of dynamite being used in each shot. Two to three shots were made every 24 hours. Fig. 17 shows the rock blasted out after the bottom of the north shaft had been blasted through, thus letting in a considerable amount of water, which was about 18 in. deep in the rock cut. Fig. 18 shows the concreting in progress, which was started at the south shaft and carried north, the north shaft being the deeper and water draining toward it, the grade being at the rate of about nine in. in 100 ft. All the blasting was finished before the concreting was begun. The progress in blasting was from 4 to 6 ft. per day. The rate of concreting in the tunnel was 12 ft. to 24 ft. per day, according to the amount of trimming to be done. The

next view, Fig. 19, is of the tunnel plastered, with 24 tile ducts installed on the west side and 12 recently installed on the east side, about half of the ducts being occupied by cable.

After the tunnels are finished, electric pumps are installed to take care of the water. These are ordinary centrifugal pumps, direct connected to $3\frac{1}{2}$ H. P., 220 volt motors running 1,800 rev. per min., and with capacities of 50 gal. per min., designed to operate under a head of 80 ft. These pumps handled the water satisfactorily and were in use about two years when it was decided to let several of the tunnels fill up and remain flooded until further cable installations should require them to be emptied. The object was to save the cost of main-

Fig. 13. Quarry St. Tunnel—Shaft Construction.

taining and watching the pumps, which amounted to one man's time and the cost of current or steam, as the case might be. The Harrison Street tunnel was the first one flooded. The prime consideration in this case, however, was to keep the cables in this tunnel cool, as they were nearly always overloaded and heated up a great deal; then, too, the cables being on racks instead of in tile a short circuit on one cable would be liable to be communicated to others. The tunnel has been filled for two and three years, and no trouble has as yet developed in any of the cables. The Quarry Street and 22nd Street tunnels were allowed to fill about a year and a half ago, and but

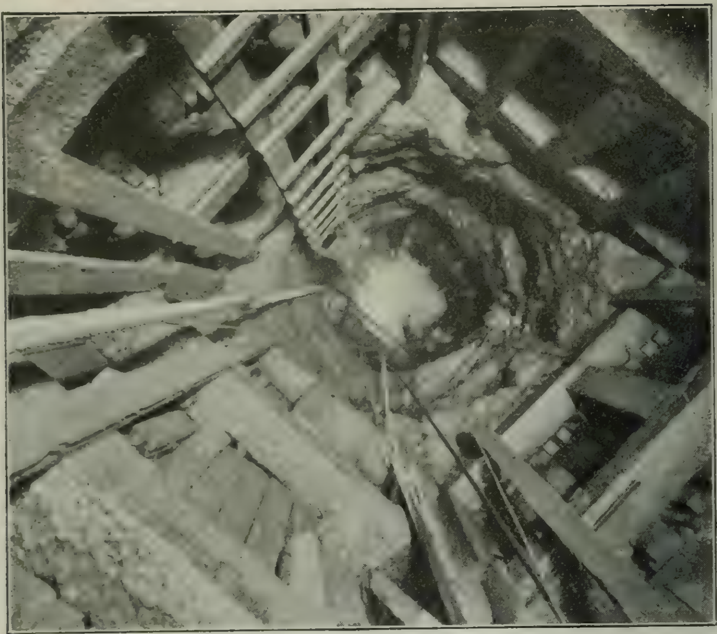


Fig. 14. Quarry St. Tunnel, Shaft Construction near Rock.

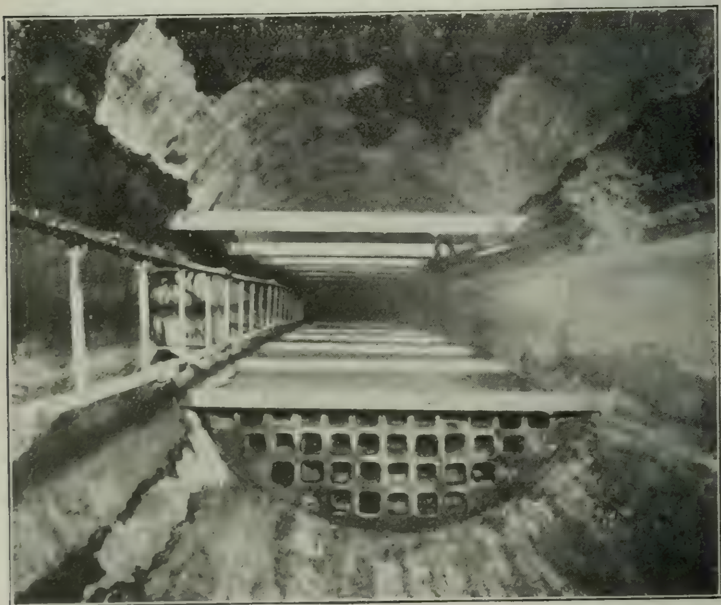


Fig. 15. Quarry St. Tunnel Shaft, Plastered.

Fig. 16. Quarry St. Tunnel, Manhole over Shaft, with Tiling.

Fig. 17. Quarry St. Tunnel—Rock Excavation.

Fig. 18. Quarry St. Tunnel, being Concreted.

Fig. 19. Quarry St. Tunnel—Completed.

one case of trouble has developed since that time. This was at Quarry Street, where several cables burned out last October.

More water enters this tunnel than any of the others and it causes the most trouble, requiring about six hours pumping per day to keep it dry. The cause of the leakage in this tunnel, as has been stated before, is the gravelly stratum about 30 ft. below datum. There is also a substance resembling petroleum which entered the North shaft in considerable quantities during construction, filling up the sump and clogging the pumps. The volume of this oily substance has decreased of late. It is thought that this is the residue from a gas plant in the vicinity which finds its way into the gravelly stratum, and thence through the shaft.

Extraordinary care was taken in building this shaft at the points where the water was in greatest volume; the concrete ordinarily mixed in the proportion of 1-3-5, being made 1-2-4. On completion, the leaks were all plastered up with cement mortar and soda ash, and confined to one point where a 2 inch pipe was inserted. Upon plugging this pipe the pressure forced the water through in several places in the shaft and through the bottom of the tunnel. The pipe was therefore, left open, the water all coming in at one point. Various methods have been tried to stop these leaks. A jetting process by which sawdust was forced behind the shafts was used, and also a bitumen emulsion mixed with cement was applied. This latter compound was tested by mixing two quarts with one sack of cement and showed an average strength of 216 lbs. per square inch compared with 317 lbs. for the mortar without the compound after seven days; also 304 lbs. with the compound, while the same mortar without the compound showed 446 lbs. per square inch after 28 days, or a decrease in strength of about 33 per cent. from the presence of the compound.

The question of waterproof concrete is a very important one to the engineering profession and deserves a great deal of attention in the future. A recent article in Engineering News, by Mr. Gaines of the New York Board of Water supply, takes up the matter of mixing clay with cement as the result of a number of experiments for obtaining waterproof concrete for the new Croton Aqueduct. It was stated, that while all preparations investigated for both surface use and used as integral parts of the concrete had proved unsatisfactory, the admixture of an electrolyte (in the form of $2\frac{1}{2}$ to 5 per cent of alum solution) and a colloid (such as 5 to 10 per cent of clay) produced a concrete practically impervious to water, and increased its strength approximately 20 per cent. The tests were made under 40 and 80 lbs. pressure of water. If these remarkable results could be obtained in practice, it is needless to say they would be of great value.

The last tunnel built was at Clybourn Place, completed in July, 1907, and is perhaps more interesting in point of unusual conditions than any of the others.

The preliminary plans as will be seen by referring to Fig. 2 con-

templated a tunnel to be built at a depth of fifty-five feet from datum to the top of the tunnel; this depth being below the piles in the foundation of Clybourn Place bridge. The borings at this depth showed a sandy loam and although this material is difficult to work in, it was thought that if not too wet, it would be stable enough to permit of the construction of the tunnel without the use of an air pressure. The west shaft was therefore started and the excavating proceeded without difficulty through the soft material to a depth of about twenty feet, when it began to get very much harder and in fact had to be chopped out with mattocks. This hard material continued to a depth of thirty-eight feet below datum, when the material began to soften, and at forty-four feet below datum we ran into a stratum of quick sand in which it was impossible to work without the use of compresed air. It was therefore necessary, either to install an air plant and proceed though the wet sand below the bridge piles, or to obtain permission from the city authorities to build the tunnel at a higher level, which would make it necessary to cut off the bottoms of some of the piles. It was decided to concrete the shaft at once, as the water and quick sand were rising rapidly, and take up with the City officials, the question of a change in the level of the tunnel.

During the concreting of the shaft, four ½ in. rods with washers at the top were built into the concrete in order to strengthen it, in the event of any settlement due to the soft foundation. A bench, or enlarged excavation was also made above the bottom in the good clay and filled in with concrete, bonding with the shaft proper, as an extra precaution to prevent settlement.

While the shaft was being concreted, the plans were changed for a tunnel in blue clay at a higher level and above the bottom of the piles of the bridge foundation, and were submitted to the City Engineer for his approval, but as was expected, there was at first some objection on his part to the changed plans, as he feared that cutting off the bottom of the piles might weaken the bridge foundation. On the other hand, it was contended by the Company that the cutting off of a small portion of the bottom of the piles would be of less danger to the foundation than the building of the tunnel at the lower depth in quick sand. The latter procedure might have created voids in the ground as was the case at 22nd Street tunnel, which voids, filling later by settlement, might have caused some disturbance to the bridge foundation. It was also pointed out that the piles had been left out entirely where the City water tunnel crossed the river; this tunnel having been built some years previous to the construction of the bridge. Furthermore it was represented by the Company's engineers that the character of the material passed through, in sinking the shaft, was of such a nature that it would not be possible to drive piles through it, and that it was extremely unlikely that any of the bridge piles penetrated below the proposed level of the tunnel.

To corroborate this theory, reference was made to the testimony of the superintendent for the contractor who drove the piles in ques-

tion, in which it was stated that most of the piles battered very badly in driving and that he thought that many of them had been shattered. The City Engineer's field notes of this job also showed that some of the piles lacked as much as eighteen feet of being driven full length.

After considering these features of the case and having seen samples of the material dug from the west shaft, the City Engineer decided that the safer method would be to build the tunnel in the clay rather than to take the risk of going down into the sand, and after several conferences, the Commisioner of Public Works issued a permit for the tunnel to be built at a distance of forty-two to forty-four feet below datum, on condition that the line of the tunnel be changed so that it would cross approximately twenty feet from the outside line of the foundation and parallel to the center line of the bridge.

This latter condition was required by the City Engineer and caused a change in the original alignment, necessitating a curve the tangential angle of which was 17 deg. 7 min., and the chord of which was sixty-two feet. This curve connected the new line of the tunnel with the west shaft.

A revised preliminary plan in accordance with the requirements of the City Engineer was filed in the City Hall, the Company retaining a copy approved by the City Engineer and Commissioner of Public Works.

The work progressed with little trouble, once the new level for the tunnel had been decided upon, and we obtained what may be called a dry tunnel; that is, one in which so little water accumulates as to be of no consequence.

That the decision of the City officials in granting a permit for the tunnel to be built at the higher level was a wise one, was abundantly proved during the progress of the work, because, of the fifty-nine piles encountered during the digging, the bottoms of only two were as low as the bottom of the bore; and of the remainder, many penetrated less than a foot into the excavation. It was supposed that some of these piles may have been split or shattered as shown in Fig. 20, but probably this is not the case because, as stated before, the evidence showed that the piles had battered badly on top in driving; also those encountered in building the tunnel were not split or battered in the least, but were in perfectly sound condition, and very little water followed them.

The record of the number cut off and amounts cut off from these piles was kept, and is as follows: thirty-one piles were cut out in the east foundation and twenty-eight in the west foundation of the bridge. Two of these piles projected clear through the tunnel excavation; thirty projected seven feet inside; twelve, from four to five feet; and fifteen, from six inches to one foot. Figure 21 shows several of these piles. They were all cut off at about a foot above the outside line of the tunnel and the space filled in with concrete, making about twenty inches of concrete on the roof where the piles occurred, instead of the regular nine inch thickness.

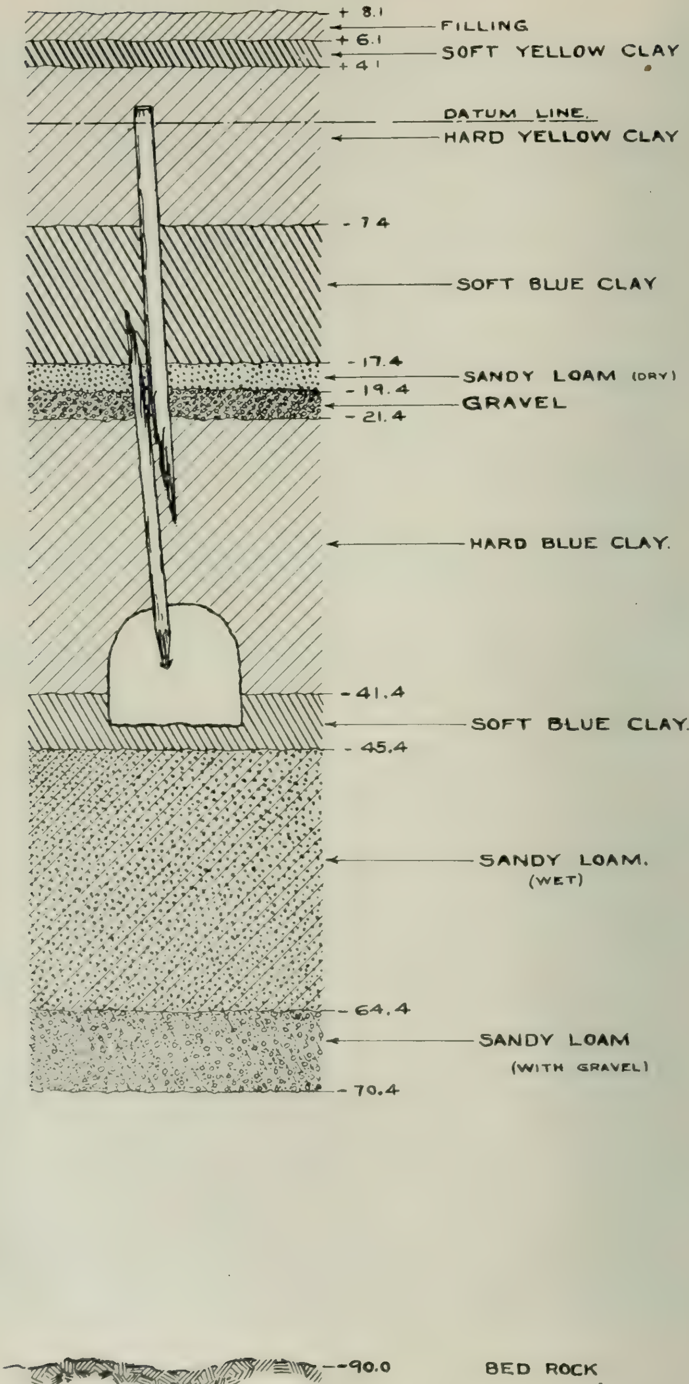


Fig. 20. Clybourn Place Tunnel—Shattered Pile.

All these tunnels were constructed with but a single case of personal injury. One of the men at Quarry Street, in attempting to adjust an arc lamp pulled it loose from its fastenings and was hit on the head by the same, receiving a fracture of the skull. Aside from this, whether from good management or good luck there were no other accidents notwithstanding the fact that a box of dynamite fell down the east shaft of Washington Street tunnel, and a drop-bottom bucket at the south shaft of Quarry Street, containing thirty sticks of dynamite, opened up, letting them fall down the shaft, but doing no damage in either case. Probably an impartial judge would decide that it was good luck which entered into the two cases last mentioned.

In the matter of alignment of all the tunnels where it was necessary to sink one shaft, then the other and drift toward the first shaft, or where the tunnel was built from both shafts toward the center, all the lines checked within one or two inches; the last tunnel at Clybourn Place checking within one-half an inch on the curve at the west shaft. The results obtained were due to the careful instrument work of Mr. F. N. Savage and Mr. J. K. Raines, who have been associated with the writer in the construction of these tunnels.

Fig. 21 Clybourn Place Tunnel with Intruding Piles

Discussion.

President Abbott: Mr. Springer mentions only one case of personal injury. There was, however, at least one other case of damage to property which came to my attention in connection with this work, which he did not mention. In the neighborhood of the Quarry Street tunnel, which is Bridgeport, the old settlers and "squatters" kept geese, and pastured them on the vacant lots. A complaint was made to me at one time that the blasting done by the contractor in this tunnel had spoiled all the eggs in that neighborhood and no geese had been hatched.

There are a number of eminent engineers and contractors present who have been connected with such work as has been described tonight, and I trust they will give us the benefit of their experience.

Mr. J. W. Alvord, M.W.S.E.: It may be of interest to hear about some tunnels that have not apparently gone ahead so successfully as those described in the paper this evening.

I am interested in the construction of a tunnel at Gary, Indiana, for water supply, which is to be 15,000 ft. long, one-half of which is to be beneath the lake and the other half beneath the site of the Steel Company's mill and under the city proper. There is to be a shaft at the lake shore, a shaft in the center of the city, and a shaft at the lake end of the tunnel. We have been about nine months attempting to get a shaft at the lake shore successfully completed, but the task is not yet finished. The ground there consists of water-bearing sand to a depth of about 35 ft. below Chicago City datum, and then clay of increasing hardness with increasing depth. The attempt to put a shaft down through this water-bearing sand seems to be a somewhat new and novel experience to those accustomed to shaft work about Chicago, where shaft work has been fairly successful.

The first attempt was made with a masonry shaft on a cast iron shoe, which went down very rapidly and successfully until the clay was reached, by removing the material inside of the shaft by means of a clam-shell dredge. The shoe penetrated into the clay a distance of about 17 ft., going harder and harder, slower and slower, and at that depth the shaft was pumped out, but the inflow of water was so great around the outside of the shaft and underneath the shoe it was not possible to carry on further excavation. After making various attempts to stop the leakage, and discussing many methods, this shaft was finally abandoned, largely because its diameter was too small to stand further reduction.

A new shaft of a larger diameter was started, in order to enable a shaft to be telescoped inside of it in case the same difficulty was experienced. It went down rapidly and easily, and penetrated about 17 feet into the clay, but the same amount of leakage was encountered. Then we tried driving steel sheeting about 12 feet in length fitted purposely for the diameter it was intended to fit, and a joint was made and the leakage was stopped. The interior of the sheeting was then concreted, and the shaft was further sunk by under-pinning,

and reached its full depth of 95 feet below Chicago datum in good ground. The tunneling was then started but difficulties were encountered with the sump, which was to be some 6 ft. below grade level, and it was discovered that bad ground existed below this sump.

After some 60 ft. of tunnel had been drifted, certain cracks developed and a certain inflow of silty and gritty water occurred, which could not be stopped, owing to the fact that if it were stopped it would rise into the tunnel through the cracks. This inflow continued until the entire lower portion of the shaft was wrecked, and the shaft was separated into two parts about 12 ft. below the tunnel. Many efforts were made to save this shaft, and many schemes as to how it could be saved were discussed, but it became apparent that it would be very injudicious to drift a mile and a half of tunnel through a shaft so insecure and so imperfect, and this second scheme has finally been abandoned.

A third attempt is about to be begun with a shaft, the lining of which will be of cast iron from top to bottom in segments about 6 feet high and 10½ ft. in diameter, bolted together. In the meantime the shaft which is in the center of the city has been sunk to grade, without encountering any difficulties.

It is apparent that sinking shafts in water-bearing sand at this depth presents some problems which have not been encountered by most contractors engaged in shaft sinking about Chicago.

In going back in my mind to some twenty years ago, when it was my fortune to be connected with the first tunnel for Hyde Park waterworks, I recall very little difficulty in the construction of shafts, but in getting down 35 feet below Chicago datum in water-bearing sand the pressures become very great and the inflow very large, with very small openings and therefore the difficulties are much greater than are usually found elsewhere about the city, where the clay is moderately near the surface.

Mr. W. B. Ewing, M.W.S.E.: I had occasion recently to sink a pumping pit through water-bearing sand at West Hammond, Ill.: the pit was 30 ft. in diameter and was sunk to a depth of about 20 ft. The wall was to be constructed of concrete 18 in. thick and the floor was to be slightly concaved, built of concrete 12 in. thick reinforced with steel rods. The water in the sand came within about a foot of the surface of the ground, which was about 8 ft. above the level of the Calumet river. In prosecuting some sewer work there, the usual method of using well points was pursued. It was first determined, in sinking the well, to construct a circular trench about 4 feet wide the depth of the well and build up the wall, then excavate the interior of the pit. The contractor, receiving some advice from another contractor on the outside, attempted to construct the wall on a light metal shoe and sink it by excavating below while placing concrete on top, but when they began to lower it the whole thing collapsed. We then returned to the original "point" method, placing points all through the center and around the sides of the well about

3 ft. apart, which kept the water down and this way we were able to excavate the well down to clay where a circular trench was dug, braced, and the forms placed into which the concrete was poured; the interior of the well then was pumped out and the remainder of the well excavated and the bottom reached without any further difficulty sufficiently dry to place the concrete floor.

Mr. C. C. Saner, JUN.M.W.S.E.: It might be interesting to mention the shaft work in the construction of the Blue Island Ave. land tunnel.

Shaft No. 1 is located just east of Lincoln Park Boulevard on Delaware Place. There is about 30 ft. of water-bearing sand at that point, and interlocking steel sheeting was driven in. First one set was driven in about 30 ft. and excavation made, and then another ring was driven inside of this and excavation made inside of this ring. The first ring did not go into the clay far enough to keep the water out. The foreman went ahead at this place and excavated to the required depth of 72 feet, and the water came in at the rate of about 60 gal. per min. between these two rings. He attempted to concrete it, and did concrete the shaft at the top with this flow of water, but it was not a success. The water came in at the rate of 35 gal. per min. I was of the opinion, before he started to concrete, that if he had drilled holes in the second ring about 5 ft. below the top, and had then dug out the clay between the bottom of the first ring and top of the second, and grouted that, and then plugged his holes, he could have stopped the water. The sheeting was water-tight and the water did not come through the sheeting, but below the first ring.

The same method was used at 22nd Street and Ashland Avenue and no trouble was encountered, but at the bottom of the first ring they encountered a heavy clay pressure which bulged out the eye beams and cracked them. A good deal of trouble was experienced in getting them back into place, in order to get the required amount of concrete.

I think, with an intelligent foreman, that these shafts can be driven through water-bearing sand by that method, but I would not advise the attempt with an inexperienced foreman.

President Abbott: It is possible that there are ways of constructing a dry tunnel in the presence of water, but it has been our experience that if a dry tunnel is desired, it must be dug in a dry place.

Mr. P. Junkersfeld, M.W.S.E.: One aspect of this question that has occurred to me is the amount of money a company has to put into the construction of these tunnels, and the amount of money taken out, either in the way of advantages as to the reliability of the general ssytem or saving in construction of other parts of the general system. It is a fact that many electrical and gas men are afraid of tackling the tunnel proposition. That is, men who distribute gas and electricity in large cities where there is a river could often make a considerable annual saving by the use of a tunnel, but they hear of the troubles encountered in tunnel construction, and put off the day.

I think Mr. Springer's paper will be especially welcome, and the "Journal" containing it will doubtless be in demand.

Mr. Springer's paper shows that in the last fourteen years the cost was cut down very greatly, and the time of building cut down from eight to three months, which indicates that it is not a serious thing to a company having men like Mr. Springer and his assistants who know how.

Mr. Springer: Mr. Junkersfeld's remarks in reference to the saving made by the use of these tunnels, reminded me of an instance in connection with the construction of the Quarry Street tunnel. The work, of course, was very difficult, but it didn't seem to be going along fast enough to suit the company, although we felt that we were making as rapid progress as we could. We could not squeeze in any more men, as we were drilling holes night and day. Finally the Assistant Chief Operating Engineer, under whom we were working, came to me and said that by hurrying the work along faster we would save the company $50.00 a day, by shutting down 56th Street station. This information served as an incentive to hurry me still more in the prosecution of the work.

Mr. W. H. Finley, M.W.S.E.: I have been much interested in Mr. Springer's description of the conditions met with in underground work in the City of Chicago. It is evident that great progress has been made in tunnel construction. I am particularly interested in the paper for the reason that the company with which I am connected is about to put in a foundation at Kinzie Street, and being accustomed to compressed air in bridge foundations we naturally favor that. The intention is to sink a pneumatic caisson 42 by 54 feet down to the bed of impervious clay that underlies the Chicago river, at about 45 or 50 feet below Chicago City datum, and from that point to sink to bed rock 10 ft. wells by open excavation, but the work will be so conducted that air can be applied at any time. If we get into any trouble on account of quick sand, we will have things so arranged that we can apply compressed air.

Our borings at that point shows at 95 ft. below Chicago datum, that over this bed-rock is gravel and coarse sand, apparently waterbearing. I would ask if any of the engineers present have had experience in sinking foundations to bed-rock, and if so, if that water is under any head or pressure?

Mr. A. Von Babo, M.W.S.E.: In relation to the Clybourn Place bridge, Mr. Springer mentions that the piles were left out entirely where the City water tunnel crossed the river, but he mentions also that additional piles were put outside, so that the pier is now eccentric. The reason for the request for change of location of the tunnel was to bring it about half way between the main supports; otherwise it was possible that the piles would be overstrained.

Mr. Alvord: I was interested in what Mr. Springer said about the mysterious disappearance of water from the Washington Street

tunnel. I can imagine that some of our friends who own artesian wells might have derived some benefit from this.

President Abbott: The disappearance of that water was one of the most unaccountable things which we noticed in connection with the construction of these tunnels. Why the water should run out of a shaft, the bottom of which is something like 90 feet below the bed of the river, is hard to explain.

Mr. Alvord: I really think that the "artesian" idea is not an unreasonable one. Many of those here tonight may not be aware that the artesian well water supply, which was at one time very abundant in this city, has of late years diminished very greatly through the increase of the number of wells and the improved methods of pumping water from artesian wells. Devices are now in use—notably the air lift—by which the water may be removed from artesian wells to a depth of 100 to 200 ft. below the surface, and it is quite possible that the proximity of some artesian well which was being pumped, so that the static level was below the level where the casing was defective enough to produce the leakage, may fully account for the disappearance of the water in question.

Mr. D. W. Roper, M.W.S.E.: There is one feature in connection with the Clybourn Place tunnel which Mr. Springer has not referred to. In driving the tunnel it was found that the permanent level of the water was very close to the bottom of the tunnel, and we made some changes. We have a sump at the bottom of each shaft, and instead of trying to make them completely water-tight we put a sewer pipe through the bottom of each one. The water was so close to the bottom of the tunnel that the water which flows in near the surface drips down the shaft and collects in the bottom of the west shaft, but as the bottom of the east shaft is a couple of feet above the permanent water level, the water flows out through the sewer pipe into the surrounding sand, and never appears above the bottom of that sump, The drainage is therefore automatic, the water flowing into a bed of dry sand which is above the permanent water level in the ground.

Mr. Saner: In regard to the pile that Mr. Springer mentions as having been driven through the roof of the Harrison Street tunnel, I would ask how far that diverged from the course it was supposed to take?

Mr. Springer: The point of the pile diverged approximately three feet south of the head. There were about five or six other piles near the one which penetrated the tunnel and by tapping each one on the head with a sledge while some one listened in the tunnel, the right pile was located. A transit was lowered into the tunnel and the angles of the tunnel as well as the ordinates of the point of the pile measured. These measurements with the location of the head of the pile were then plotted and the divergence scaled. The length of the pile was fifty feet.

THE RAILWAY TRACK OF THE PAST, AND ITS POSSIBLE DEVELOPMENT IN THE FUTURE

J. W. SCHAUB, M.W.S.E.

Read May 29, 1907.

If you have ever noticed the approach of a heavy train on a modern railway by keeping your eye down near the track, you could not have failed to notice the extraordinary wave in the track which is formed in front of the engine. This wave appears to be about twice the height it actually is, as it is formed not only by depressing the track immediately under the engine, but the track immediately in front is actually lifted, thereby forming a true wave motion. If the train is moving at a high rate of speed as it passes, you will be impressed by the noise and the lack of rigidity of the whole structure. The cause of this wave motion is the yielding of the track. The dynamic action of the moving load must be absorbed by the rails, the ties, and the substructure underneath. This tends to push the entire track in front of the wave, and this yielding of the track accounts largely for the creeping of the rails. If the ballast is hard and frozen, as well as the substructure underneath, the rails must absorb the bulk of this energy, and if the conditions are such as to produce an uneven hardness, such as a sudden frost in earth full of moisture, when combined, perhaps, with a low joint, the chances are that a broken rail will result.

The railroad commission of the state of New York reports that over 3,000 rails were broken in that state during the past January, February and March. These breakages are reported by the railroads themeslves, so that they can be considered as authentic. This means that over 33 rails per day were found broken, or one rail per day for every 240 miles of track in the state of New York alone.

The railroads are so alive to this condition that they are patrolling their tracks day and night in order to forestall the danger presented by a possible broken rail. How does this appeal to you from an engineering standpoint? Imagine a stationary engine, developing at times 2,000 horse power, on a base or foundation which is so uncertain that you are compelled to have someone watch it day and night in order to forestall the danger of a wreck to the machine itself, to say nothing about the gravity of the situation when this wreck becomes a matter of life or death, every time. The *Railroad Gazette* has given this subject a good deal of attention, and in a recent issue publishes a collection of letters bearing on this subject, from a number of railroad officials. These letters are in answer to a request to give their views as to the cause of

the great increase in rail breakages, and with one or two exceptions they all blame the poor quality of the steel. One letter, the shortest of them all, is by far the most instructive. Quoting from the above issue, "I should say, the quality of the rails furnished is gradually getting worse and the axle load of engines and their speed is gradually increasing." In a few words this correspondent sums up the whole situation. "The rails are getting worse, and the loads are getting heavier"; so that, there are two sides to this question and both sides should be given due consideration.

An examination of the rails shows the breakages usually occur near the ends of the rail. Some show flaws due to "pipes," or a lack of weld owing to the presence of some foreign substance. These flaws correspond to "cold shuts" in the days when iron was used. Others show fractures due to brittle steel, and still others the characteristic coarse crystals due to imperfect physical treatment. Of these fractures the ones due to the brittle steel are most to be feared, as they are most insidious. The "pipes" and the imperfect physical treatment can perhaps be guarded against, but what can be done to guard against a brittle steel?

Steel is brittle, as a rule, owing to the presence of phosphorus; but, the rail manufacturer says that phosphorus has been gradually eliminated, until now it is at least 25 per cent less than it was fifteen or twenty years ago. But what of the carbon? In the last few years the requirements for carbon have been increased by 100 per cent. It it safe to make a high carbon steel, carrying 0.60 per cent of carbon, in the presence of 0.10 per cent of phosphorus? In other words, has the phosphorus been eliminated sufficiently to compensate for the increase in carbon? The railroads should insist upon a reasonable limit for phosphorus and make the rail manufacturers live up to it. Just now it would be interesting to know why the railroads have to accept the manufacturer's standard.

No concerted effort has been made to analyze this problem, other than to blame the rail manufacturer, for the poor quality of the rails, but there is another side to this question that has not received proper consideration. Quoting from the excellent paper on track superstructure by Mr. O. E. Selby, bulletin No. 80, American Railway Engineering and Maintenance of Way Association, "Railroad track has grown in strength as heavier loads have made increased strength necessary, but such growth has been entirely along empirical lines, and not one single detail of track superstructure bears marks marks of engineering design."

To begin with, is the difficulty due entirely to the poor quality of the rail? We have heard much of the speed with which rails are rolled, and of the high temperature of the steel when on the cooling bed. This may account for some of the difficulty; but, on the other hand, is the structure upon which the rail rests free from blame?

To be sure the quality of the steel can be improved, but so can the substructure upon which it rests in the track. If it is true that the heavier rail sections have shown a higher percentage of breakages than the lighter sections, under the same conditions, then the cause of the rail breakages should not be hard to find.

Increasing the weight of the rail in a track does not necessarily make a better track than a lighter rail does. Something must be left for the ties, ballast and substructure to do. If the original form of railway track, with its strap rails laid on longitudinal timbers resting on cross-ties, had been developed along these lines to its logical conclusion, the present form of railway track would have been unknown. Let us see what are some of the defects of the present cross-tie system of rail support. In the first place it is not mechanical. Given a line of rails which have to carry moving loads reaching 20,000 or 30,000 lbs. and more per wheel, the loads which they carry must be distributed over large areas. The cross-tie system accomplishes this by inserting 16 to 20 independent supports under each 30 feet of rail, and upon the track department is placed the impossible task of so adjusting these supports that each shall bear an equal part of the load. This is the real secret of the enormous amount of labor spent on surfacing a track, in order to carry trains at high speeds, and it is a work that goes on forever. Moreover, assuming a joint has not been kept up to surface, what happens when a wheel passes over it? Within certain limits the ends of the rail will deflect until the tie receives a firm bearing; and, all track shows, more or less, the effect of the lack of continuity in the rail, by the dip of the rail at every joint. This happens in an instant, when the operation is repeated by the next wheel, and so on. (Fig. 1.) Assuming the deflection of the end of the rail to be Δ when the tie reaches a firm bearing:

Let "W" be the wheel load;
Let "l" be the space between the supports;
Let "E" be the modulus of elasticity of the steel;
Let "I" be the moment of inertia of the rail section;

$$\text{Then } \Delta = \frac{W l^3}{3 E I} = \frac{(W l) l^2}{3 E I} = \frac{M l^2}{3 E I}$$

Let "f" denote the fibre stress on the rail due to bending;
Let "y1" denote the distance from outer fibres to neutral axis.

$$M = \frac{f I}{y_1} \therefore \Delta = \frac{f l^2}{3 E y_1} \therefore f = \frac{3 E \Delta y_1}{l^2} \quad . \quad . \quad . \quad (1)$$

Equation (1) shows that for a given deflection of a rail the fibre stress varies directly with the distance of the outer fibres from the neutral axis, and nothing else. In other words, if the rail deflects until the tie brings up on a firm bearing, regardless of the wheel load, then the stiffer the rail the more work it will be called upon to do, and consequently the higher the fibre stress on the steel will

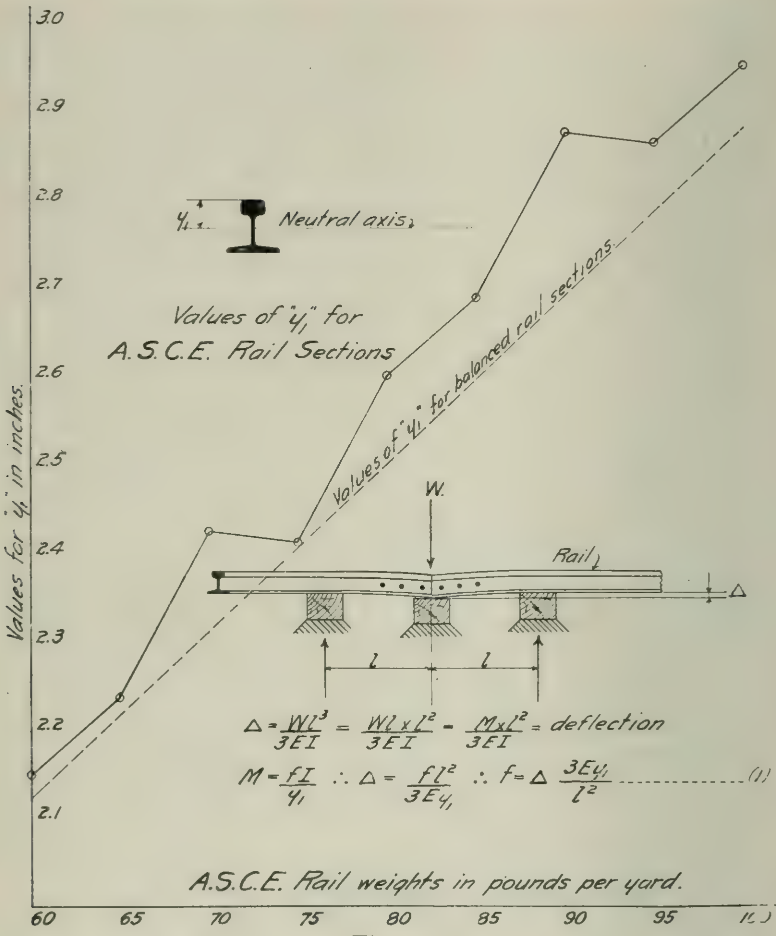


Fig. 1.

be. Now, is this not approximately what takes place under ordinary conditions? The load comes on the rail, and if the rail lacks a firm bearing it will deflect until it finds a reaction. Equation (1) tells us that in order to reduce the work done by the rail it will be necessary to reduce the value of "Δ." In other words, make the ballast and substructure as unyielding as possible so that the rail will be relieved from a duty which it is not qualified to perform, and which it should never have been called upon to perform.

To illustrate, let us assume that a fibre stress of 15,000 lbs. per sq. in. is acceptable for a working load, and "y_1" for a 60 pound rail to be 2.15 in., E = 30,000,000, and "l" = 40 in.; then for a 60 pound rail,

$$\Delta = \frac{15{,}000 \times 10{,}000}{3 \times 30{,}000{,}000 \times 2.15} = 0.124 \text{ or } \tfrac{1}{8} \text{ in.}$$

Whereas, the fibre stress for an 80 pound rail corresponding to a deflection of an eighth of an inch is 18,000 pounds per square inch. In other words, for the same deflection, the 80 pound rail should have 20 per cent more breakages than the 60 pound rail, all other conditions being exactly the same. To be sure, this is only approximately true, but it goes to show that if the track could be made as smooth and unyielding as a planer table, an ideal condition would be realized. If this is true, then the railroads are wasting their money in buying heavier rails.

In passing, it might be well to call attention to the deficiencies in the standard rail sections, known as the A. S. C. E. rail sections. In any cross-section of a beam subjected to bending, the distance of the outer fibres from the neutral axis should be the same, both above and below, in order to have the extreme fibres above subjected to no higher stress than the extreme fibres below. In other words, the section should be balanced, that is, the center of gravity should be in the center of the figure. This is fundamental.

Referring to Fig. 1, it will be seen that all of the standard rail sections are unbalanced sections, with the result, that in the case of the 90 pound rail, the metal in the head receives a fibre stress 15 per cent higher than in the flange.

In a recent proposed section for a 100 pound rail, which has been adopted by one of the trunk lines, this difficulty has been increased instead of being diminished, with the result that the metal in the head will be subjected to a fibre stress 24 per cent higher than in the flange. This difficulty can be remedied by revising the rail sections so as to put the center of gravity in the center of the figure, without reducing the efficiency of the rail as a beam, and at the same time observing the requirements of the section from a metallurgical standpoint.

But, the usual argument against an unyielding roadbed is offered by the railroad manager about as follows: He says the track must be elastic, otherwise the rails would be destroyed or broken, and therefore the present form of track must be maintained. Yet this same manager will order the heaviest rails to be placed in the track, to be supported on the heaviest ties that he can procure and laid on the deepest ballast, to make a firm and unyielding roadbed as near as can be made by such devices. If a rail could be laid on a solid bed uniform throughout its entire length, so that every part is supported exactly the same as every other part where will the rail break?

But how shall a roadbed be built that will meet such conditions? In the first place, the substructure upon which it is to be laid must be absolutely unyielding, and its foundation must be free from all

moisture or below the action of frost. In some cases concrete walls must be built upon which the superstructure is to rest. In other cases piles must be driven, each case being treated as the conditions require. Upon this the superstructure must be laid. This must be some departure from the cross-tie laid on ballast. Nothing can be expected from any longitudinal support laid on ballast, for it can be shown that unless some transverse support is given to the longitudinals, it will be impossible to keep such a track in surface.

Fig. 2.

In the *Railroad Gazette* for March 15th, 1907, there is published an article by Mr. Gustav Lindenthal, M. Am. Soc. C. E., showing a form of steel longitudinal support for track rails. (Fig. 2.) This shows a rock ballast under two longitudinals, covered by a sand or gravel filling. Think of putting down a bed of clean rock for ballast, and then covering it with sand, as though the difficulty in keeping the ballast clean is not enough without mixing it with sand. Referring to the cross-section of the steel longitudinal system shown above, it will be seen that when the system is in place as the author shows, there will be a nice little prism of broken stone supporting the steel girder upon which the rail is to rest. Now when, with a good deal of labor this broken stone is packed into just the right shape why not put something into it that will keep it there, instead of having it jarred out of place by the traffic. This form of track is being tried experimentally by the Pennsylvania Railroad on the Philadelphia Division, and the experience they are having with it is exactly as should be expected. It is impossible to keep such a track in surface. The reason for this is not difficult to find. Just turn the cut showing the cross-section, upside down, and if you assume the pressure on the ground as uniformly distributed, you can at once realize the tendency of the prisms under the rails to flatten out, and this is exactly what takes place in this form of track today. The system of longitudinal support will never prevail unless combined with some transverse support.

But how can this be accomplished? Take the present form of track, with cross-ties sawed to dimensions and surfaced on one side to uniform thickness, laid on a rock ballast at least 16 inches deep. Insert steel I beams temporarily under the ends of the ties, so that each tie will have a full bearing on the beam at each end. Fig. 3.

The steel beams are to be of the "Special" type with broad flanges to be rolled by the Bethlehem Steel Company. The beams are to be tied together by tie rods spaced two feet centers, so as to confine

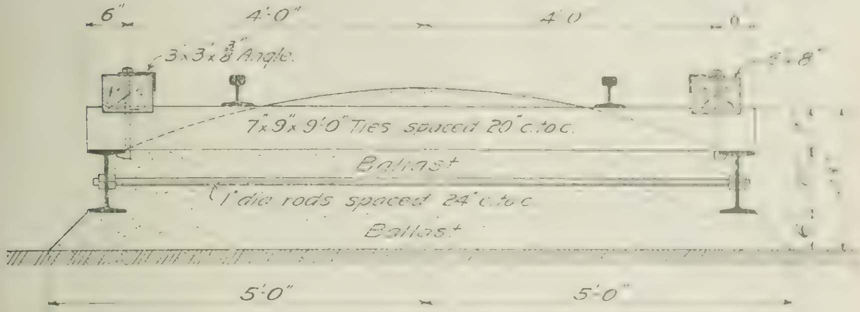


Fig. 3.

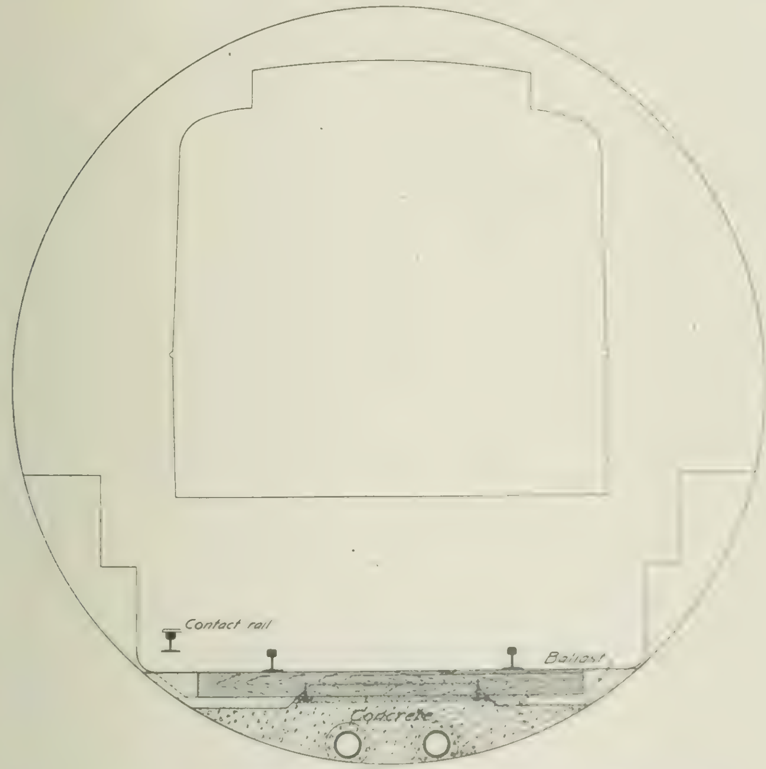


Fig. 4.

Proposed Track for East River Tubes, adapted from London Tubes.

the ballast between the beams. On the ends of the ties previously laid, place a bond timber, notched over the ties at least one inch, and hold the same down by means of a hookbolt, passing through the tie, and anchored to the inside flanges of the beams. An angle iron nosing on the inside of the bond timber serves as a guard rail. After all is in place, the extraneous ballast, that outside of the beams, is removed. No part of this operation need interfere with traffic. In bringing such a track to surface, the entire structure is to be lifted by means of track jacks placed under the flanges of the beams. After the ballast is once in place, very little work should be necessary to keep such a track in surface. The ballast is confined between the beams, so that an arch action can take place, with the thrust of the arch taken up by the tie rods. This assumption makes it possible to find the tension on the rods and properly proportion them.

But, how does this form of track offer any advantage over the

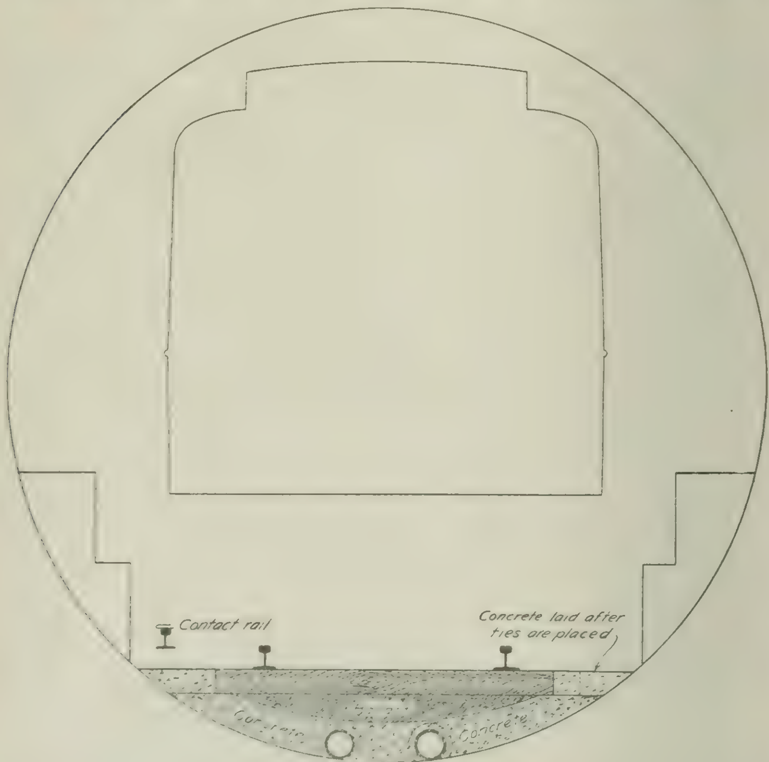


Fig. 5.

Proposed Track for East River Tubes, Rapid Transit Subway Construction Co.
Geo. H. Pegram, Chief Engineer.

present form of track? Solely in the introduction of the longitudinal beams. These beams are to perform two distinct functions. First, the special beam, with its broad flanges, having a moment of inertia equal to five times that of an 80 pound rail, and with 8 per cent less metal, should do just five times the work done by the rail when both are working together under the same conditions, neglecting the work done between the cross-ties in either case. The work done by the rail would then be principally to distribute the load over the ties, and not to make up for the deficiencies in the substructure, as it does now. Second, in confining the ballast, and thereby preventing the track structure from working its way down through the ballast, as it does now in the present form of track; where under heavy traffic, the ballast is kept in constant motion during the passage of trains; and, as the particles of the granular mass are free to move, they follow the lines of least resistance, that is, out from under the ties. This explains why the

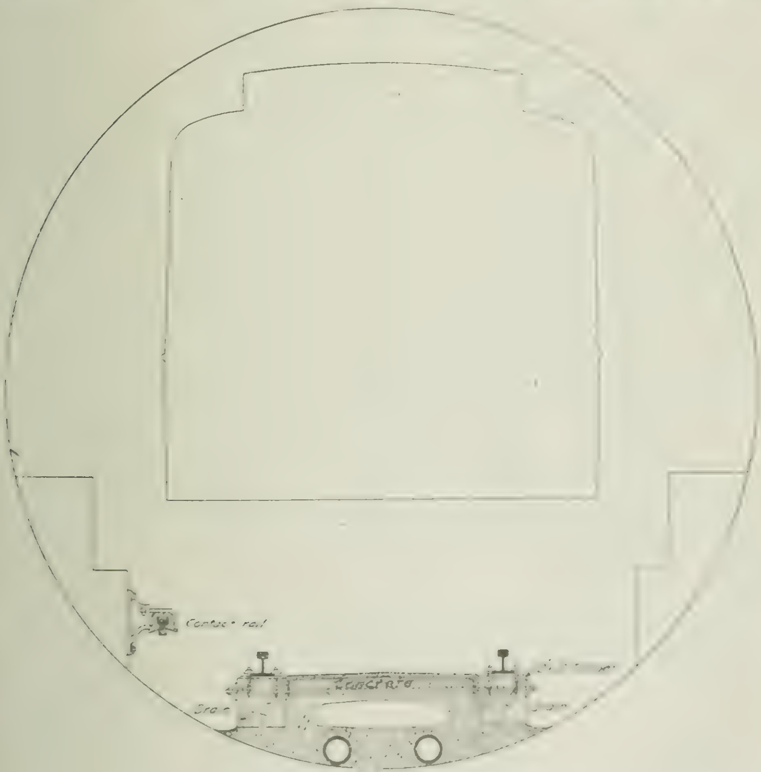


Fig. 6.

Proposed Track for East River Tubes, submitted by J. W. Schaub, C. E.

ballast is so unstable, and accounts for the enormous amount of labor necessary to keep a track in surface and alinement. With the proposed form of track, on a solid substructure, this should largely disappear. After this form of track has been proven by experiment to be correctly designed, the timber should be removed, and the ballast replaced by concrete, flush with the tops of the beams, forming a permanent substructure upon which the superstructure is to be placed. At the same time the steel beams can be removed. This superstructure should be some form of longitudinal support bedded in concrete, so as to distribute the loads over large areas, offer perfect drainage and be absolutely imperishable and unyielding.

DISCUSSION.

Mr. W. A. Field: Mr. Schaub's paper is a very interesting one. All I know about the question of the advisability of making a solid foundation for the road-bed is what I have gathered from talking with Mr. Griswold. It has been found on some of the roads where stone ballast has been placed, that the substructure will not hold moisture, and therefore does not freeze in the winter; however, during the winter months I understand the breakages are greatest; also that the rails laid on that kind of substructure stand up better because there is more elasticity than in roads where ballasted with gravel, and which in the winter time freezes into this solid condition mentioned. The breakages, however, on the roads with gravel for ballast have occurred mostly on one side of the track, and it has been found that the drivers of the engine last passing over it were out of balance so many units in measurement. What I am trying to get through my mind is what is best to adopt as standard for substructures in winter when we know it will freeze, and at the same time give a certain amount of elasticity to the track.

We did lay a 100-lb. rail on a solid concrete foundation in which was imbedded, at the usual standard spacing, short ties—say, 24 or 30 inches long—allowing the rail to come in contact with the concrete in the intervening spaces. We were running over these rails very heavy ore-unloading machines, and our experience for the first season was that they gradually flattened out until the rails increased in width of head about one-half inch. I do not recall the wheel loads on those unloaders.

Mr. W. H. Finley, M.W.S.E.: Were they not excessive?

Mr. Field: Yes; however, the engineers who designed them figured that the wheel load was not excessive for the fibre strain of the steel of the track. We braced them up, however, and put shims all over them so there was a wooden strip the whole length of the track, which gave the effect of sort of a cushion. Since then the rails have not played out as rapidly as before. It is hard to make a general statement of just what would be the best standard to adopt.

Mr. Finley: If those rails were first laid on an unyielding foundation there was no fibre stress involved.

Mr. Field: I accept your amendment.

I question one thing in Mr. Schaub's report. I think that that crystallizing might be due to the pounding on the rail; that metal has been in the track four years for the use of a high speed railroad, and it is a serious question whether the steel was of that character when it went into the track. We find in the rollers on the tables at our mills that after a certain time the bearings will fall apart like a piece of glass, and after the continued pounding with the heavy weight passing over them they will break off, and show the most beautiful crystalline fracture,—just like a piece of rock crystal.

Mr. F. H. Drury, ASSOC. M.W.S.E.: A great majority of the breaks occur near the end of the rail. If you eliminate the inherent weakness in the joint, so that the joint of the track is as strong as the rail itself, have you not eliminated the great danger of breakage? If by puting supports in the side, additional to the tie plate, and bolting supports underneath so that the joint is made as strong as the rail itself, no matter how heavy the load going over it, there will be no great deflection at the joint. In this way will not the greater part of the danger be eliminated?

Mr. Schaub: That question can be answered by examining any standard track when you will find the characteristic dip in the rail at the joint. You may not be able to see it with the eye, but it is there because no joint is made as strong as the rail.

Mr. Drury: But if the joint *could* be made as strong as the rail, then I presume that difficulty would be overcome.

Mr. Finley: Mr. Schaub, in starting out in his paper, stated that an observer of a track with a heavy load passing over it could see that wave action, yet he assumes for his deflection that it fulcrumed around the adjoining tie. I do not think that follows.

Mr. Schaub: The assumptions made do not give the actual deflection, and are only approximately true. If you assume that the rail bends between two supports, or at a joint until it finds a bearing, the deflection will be independent of the weight of the rail. Within certain limits this must be true.

Mr. E. N. Layfield, M.W.S.E.: Mr. Schaub's idea is based on the assumption that there is an exact point where the rail will stop deflecting, and that will be the same whether the rail is light or heavy.

Mr. Schaub: That condition would correspond to that of a low joint.

Mr. Layfield: But with a light rail the deflection would be greater than with a heavy rail. If there were a bed below the tie absolutely fixed and solid, that would alter the case, but such conditions do not exist. The end of a light rail, as a matter of fact, does go down lower than a heavy rail.

Mr. E. E. R. Tratman, M.W.S.E.: It is rather a curious fact that after all these years no track has been constructed as an engineering structure for experiment. We have experimented upon bridges, tunnels, locomotives and cars. But with the exception of a compara-

tively small increase in weight of rails, the track is now what it was twenty-five or thirty years ago. It would be interesting and instructive to have some practical trials made with the substructure as proposed by Mr. Schaub, or various other proposed constructions, because as a matter of fact, we have very little knowledge of anything but the simple combination of rail, tie and ballast in track construction.

Mr. W. M. Camp: I think Mr. Schaub has certainly put forth a new idea when he claims that the fibre stress in heavy rails, like 90-lb. rails, theoretically should be greater than what it is in 60-lb. rails under the same loads. Possibly such a conclusion may all be due to his assumption that the tie is going to be depressed the same depth every time the wheel load pases over it, without regard to the stiffness of the rail. From a practical standpoint the heavier and stiffer rail should distribute the load over more ties than the 60-lb. rail. I therefore think it wrong to assume that the ties will be depressed as far under the 90-lb. rail as they will be under the 60-lb. rail.

I hardly think it fair to bring up at this time the question of broken rails as evidence of a wrong type of track structure. It certainly seems that the record of broken rails shows the trouble to be in the quality of the metal. The majority of rails which have broken during the past two or three years have been 90-lb. or 100-lb. rails, and there have been comparatively few 60-lb. or 70-lb. rails broken.

The gentleman who seems to be talking from the standpoint of the mill man raised the question whether the action of the traffic would not crystallize the rails. That matter has been looked into a great deal, especially in England, but there is no proof that crystallization occurs. Some ten or twelve years ago there was a bad wreck in England caused by a broken rail, it having broken into several pieces. The question was raised whether the rail, which had been in service for a long time, had not been crystallized. It was found that the metal in that particular rail was very brittle, but examination of other rails in the same track, which had seen the same length of service, found no evidence of crystallization of steel below a very minute depth on top of the rail, something like a depth of 0.01 of an inch—which was understood to have been caused by the cold rolling from the wheels; but whatever change there might be in metal to that depth would make no sensible difference in the strength of the rail. I believe the question has been investigated to some extent in this country, but it has never been established that the action of the traffic will change the crystallization of the metal from what it was when the rail was manufactured.

That man Wohler, who performed his experiments by reversing the stress so many million times on steel and finally rendering it brittle, has caused no end of discussion on the question of the "fatigue of metal," but, so far as rail and bridge steel are concerned, it has never assumed anything more than academic importance.

With reference to Mr. Schaub's proposed track, I hope that some

railroad will take it up and experiment with it in actual service, to see how it will work. That is the best that can be said for it. One cannot tell what a proposed construction will do until he has seen it in service, unless it is so very bad that it is worthless on the face of things.

It is true that a great deal of expense in maintaining track is caused by the ties settling into the ballast. Of course, if we have a concrete bed for the ties they could not settle into it without breaking up the concrete. However, if one examines into proposed construction carefully, the first question is, have we after all, a good foundation for the track? The reason that the cross-tie type of track is standard the world over, is because it affords facility for repair of track surface. How is one going to get a solid foundation for track? Through a rock cut we may get it, but what is one to do on a fill? There one must lay the track on soft material, and that is the best that can be done. How much better off are you, if you put a slab of concrete on top of that? We know what frost does when it gets under concrete sidewalk. Suppose that frost gets under the concrete slab which supports the track? Will it not heave like the concrete sidewalk? From the lantern view, I infer that the depth would be something like 2 ft. Of course, if you can keep water from it, that will be an important point gained, but when one considers a heavy load running at high speed, the question arises whether it would not be liable to break up the concrete bed. I do not think Mr. Schaub would propose to lay that track on a newly built embankment. If he did it would settle and require raising to surface frequently.

Mr. Schaub: Do you not think that the breakage of rails is a particularly heavy expense?

Mr. Camp: Yes, but the railroad companies are crediting that trouble to the mill men. If we can get rails that will not break, that question will be disposed of.

You must bear this in mind with reference to track: It is on the surface of the ground, and while the stiffness of the rail helps to support the track, it does not do all the supporting. The ground must be relied upon to some extent for what we call "beam strength," and the deflection of the track downward produces a wave motion in the ground. Some engineers seem to think that ballast affords extra stiffness over that of the ground in its undulations when a load is passing. I doubt it; I question whether a layer of gravel is as stiff as a layer of well compacted soil of the same depth.

As for providing a stiff structure to support the track, one has the rails and the ground, and of course, the ground is very variable in supporting strength. Through a swamp it is quite weak, and in a rock cut it is at its best; so there are all sorts of conditions of support under the track.

It seems to me that the most important question in connection with Mr. Schaub's construction is whether the slab of concrete is going to afford enough extra stiffness, combined with that of the ground

and rails to eliminate undulation entirely. If it does not eliminate wave motion there will be the liability of having some broken concrete.

Mr. Field: Mr. Camp states that the rails he had seen broken were 90 and 100-lb. rails. Have you been running sixty to ninety miles an hour with Atlantic type engines over any of the 60-lb. rails?

Mr. Camp: Yes, that was done ten years ago. There is a misconception regarding the increase in wheel loads. Wheel loads have increased, but not overwhelmingly. About ten years ago the average driver load of passenger engines being built at that time was a little less than ten tons. That was heavier than the average driver loads of the freight engines. Five years later the average load had increasd to about $11\frac{1}{4}$ tons. At the present time the average driver load of passenger engines is somewhere between 12 and 13 tons, with 15 tons as the extreme in a few cases. While we have many engineers weighing over 100 tons, we must take into consideration that they have more wheels than formerly. By putting trailers on the eight-wheel engine we have developed the Atlantic type; and by putting trailing wheels on the ten-wheel engine the Pacific type has been produced, and so on. With increase in weight of locomotives there has come about the practice of using trailing wheels behind the drivers, so that axle loads or wheel loads are not as heavy as they would have been had the same increase in weight been made by piling up weight on wheel bases of the old types, even if such would have been done. The extremely heavy locomotives, or those weighing more than 125 tons, have the Mallet articulated wheel base with the weight distributed on twelve or sixteen driving wheels, so that the wheel loads are really no greater than with some locomotives of ordinary types but a good deal lighter in total weight.

It is true that the average speed of today is somewhat faster than that of ten years ago, but not so much as is someimes stated. Speeds of 60 miles an hour and higher were made 25 years ago, but that was not an average speed, and no train in this country is making that as an average speed today, although 70 to 80 miles an hour is common, between stops.

Mr. Field: I have had many arguments in regard to the 18-hour train to New York. Certain parties have told me that they had kept time between stations riding on both the 18-hour and 22-hour trains, going and coming, and they say that the train that takes four hours longer makes four hours more stops and runs at about the speed of the 18-hour train; however, this information may not be correct.

Mr. Camp: If course, trains today run considerably faster than they did some years past, but even twenty-five years ago it was frequently the case that a train would run 60 miles an hour—even freight trains did it sometimes "between stations." You will find that wheel loads are about 25 per cent. heavier on an average than ten years ago, and the average speed of through passenger trains,

taking a number of roads into consideration, perhaps 10 or 15 per cent. faster.

Mr. Field: This question of segregation has been gone into by steel manufacturers all over the world. I venture to say the Germans have investigated it to the limit. We Americans go to Germany and find that patents have run out there on processes we have evolved here and thought were new. There is such a thing as segregation. You will find segregation in both Bessemer and Open-hearth steel. You do not find as much in the lower carbon steel as in the higher. When I first started in the mill business in 1891, anything that was steel went into rails. The railroads made no specifications because the steel made then stood up ten or fifteen years. The first rails I remember of having been taken up were said to have been in fifteen years.

Mr. Finley: Do you think the manufacture of rails was better then than now?

Mr. Field: It has not been changed at all.

Mr. Finley: Is the mechanical treatment also about the same?

Mr. Field: The rolls are the same as years ago; we have the same engines which make the same number of revolutions.

The question comes up as to the speed with which rails are manufactured. If you multiply the number of revolutions of the engine by the periphery of the rolls and put a continuous stream or bar of rails through there, we would make three thousand tons in twelve hours, theoretically. The old conditions were that they did not have a sufficient supply of steel to begin with. They rolled an ingot and had plenty of time, but that ingot went through at exactly the same speed as today. This fast rolling is not due to speeding up the machinery, but to the elimination of delays that have existed before. We have one ingot closer to the other than before. We figure that we get more work on a rail, and that we are making better rails than ever before.

Mr. Finley: Do you think better results are obtained from Open-hearth than from Bessemer steel under present conditions?

Mr. Field: I do not know anything about the results that have been obtained from the rails made at Ensley, Alabama. I have heard varying reports. I do know this,—that if the carbon was reduced the breakages would decrease, but the wear of the rail would probably increase.

With reference to high speeds, I noticed the other day some rails at the Sixtieth Street Station, Illinois Central R. R., which were made in 1896; they were just as smooth as glass and will be there ten years from now.

Mr. Drury: I cannot help but think that the breakages are due more to the foundation than the rails themselves. My experience is perhaps old, because of late years my work has not been along these lines. In 1880 I was connected with the road department of an Eastern railroad. We did not have a broken rail a week. I came

out West in 1882 and was connected with a Western railroad; we used to figure that we were getting out lucky if we had no more than two or three a day, but the track was in much poorer condition, so I cannot help getting back to the fact that if you can make the joint as stiff as the rest of the rail you are going to have your rail motion continuous from time to time; then I think you will have possibly an ideal track.

Another thing we have to consider is that the economic conditions are such that nine-tenths of the railroad companies will never be in a position to adopt any such elaborate system as concrete foundation of superstructure as outlined. I think nine-tenths of the railroad tracks for the next hundred years will have to be built on top of the ground and that the ground is the best foundation there is.

Mr. Field: I think this,—when railroads begin to specify open-hearth process they will have to begin at a reasonable percentage of carbon and feel their way up. Whether the Bessemer process is at the end of its career or not, I do not know.

Mr. C. V. Weston, M.W.S.E.: I would ask Mr. Field in regard to the wear of rails under similar conditions of traffic. I have been engaged in building a type of railway for city transportation where there is not the excessive load that occurs on steam roads, but, over and against that, we do have the frequency of service. We have been maintaining track on rather sharp curvature under this traffic, and up to four or five years ago, under practically uniform conditions of traffic, we obtained from eighteen months' to two years' wear out of the rails. Today, under nearly similar conditions, we are renewing the rails on those same curves in from eight to ten months.

I have been trying to get some reliable information on this subject and have several times submitted it to manufacturers of rails, but they have never given me a real answer to the following question: why, under the same conditions of traffic, on the same curves, at the same rates of speed do we get only half as much wear out of the rails as we formerly did—the weight of rails and the specifications under which they are manufactured being almost identical?

Mr. Field: I have never heard any arguments in that connection. What is the reason that with more passes you make a better rail than with less passes?

Mr. Finley: The more processes you put the rails through the more the mechanical work, and you would get the same result that you do in forging. But is it not a fact that by putting the steel through a greater number of passes you would get that much more mechanical work on it, more of that forging work, making the metal denser?

Mr. Field: From microscopical examination of cross sections from different passes, there is a denser condition of the metal all the way down and more uniform condition on the outside of the rail now than formerly.

Mr. Finley: In regard to the question of crystallization. That

has been a strong subject among engineers and Mr. Camp mentions that experiments of railways have, in a way, settled the matter. I would ask Mr. Schaub if, in his opinion, any repeated stress of material within its elastic condition will produce crystallization?

Mr. Schaub: When a wheel rolls over a rail, which is properly supported and the load is heavy without producing abrasion, the rolling action should really reduce the crystallization. It is a process of cold rolling and there is no evidence whatever that crystallization is produced by the wheel passing over the rail.

Mr. G. H. Bremner, M.W.S.E.: Nearly every engineer who has investigated track matters can bring to mind examples, showing the poor quality of rail now being made.

I recall where we have a stretch of 85-lb. rail, which has been in the track two years, and beside it in the same track, under similar conditions, is a stretch of 85-lb. rail which has been in the track twelve years, and the Roadmaster is of the opinion that the rail which has been in the track twelve years is the better of the two and will stand more wear. It is general knowledge that the lighter rails will stand comparatively more wear than the heavy ones. The 66-lb. rails (of which we have a great many), wear better and do not, comparatively, break as readily as the 85-lb. rails; a 56-lb. rail is often a better wearing rail than a 66-lb. rail. Not that the 56 or 66-lb. rails would be good for very heavy engines on account of their lightness, and on account of their lack of stiffness, not acting as a beam as the heavy rails do. The recent breakage of rails does not appear to have occurred with the greatest proportion of breaks at the joints. In the last six months I have noticed that more rails have broken between the joints at the middle of the rails than at the joints.

Mr. H. G. Griswold: I have noticed one fact, that the breakages are always largely on one side of the track in any particular case. In one instance 143 breaks occurred in a night; 142 of these were on left hand side of the track. The breaks did not occur chiefly at the ends, but all along at various parts; as many breaks at one part of the rail as another. I have investigated five or six of the largest breakages, and in every case they were practically all on one side of the track. They occurred in very cold weather when the roadbed was frozen solid, and at points where speed was very high. In the case where the 143 breaks occurred the speed was at about ninety miles an hour. The engine that did the breaking was located by the failures of the automatic block signals. The Mechanical Department could not find anything wrong, but there must have been something wrong on one side. From the counterbalance record of the locomotive, as it left the locomotive works, we figured that at 90 miles per hour the wheel load would vary, due to the disturbance generated by the counterbalance weight added to balance the reciprocating parts, from 10,500 pounds to 41,500 pounds, six times a second. At sixty miles per hour the variation was much less; as the speed increased the variation was more; this is with the engine in perfect

order. With a driving wheel out of round there might be such a variation as to actually lift the wheel off the rail.

We also figured on another type of egnine—an Atlantic type—and found at a speed of ninety miles an hour the pressure between the front driving wheels and the rails varied from 4,000 to 48,000 pounds, six times a second. If the engine and track were in perfect order the wheel would not lift off the rail, but if the wheel were a little out of round it might lift off the track, and if a wheel is lifted in this way, something is liable to break when it comes down, as it would descend with a true hammer blow. The maximum pressure of the main driver, when using steam, was about 57,500 pounds.

Mr. Schaub: I think the whole difficulty is not in the high carbon. About ten or twelve years ago I happened to be a witness in a law suit brought against a pipe company; certain pipe had been condemned on account of the high phosphorus. An analysis was made of the pipe, when it was discovered that there were ten points of phosphorus in the pipe, and the customer refused to pay for it, which resulted in a law suit. Testimony was given on the stand by one of the pipe manufacturers, who was entirely disinterested in the matter, to the effect that, owing to the low carbon in the steel (the pipe was lap-welded), it was necessary to have at least ten points of phosphorus, in order to cut a thread on the pipe. The case was won by the manufacturer on that testimony.

The American Society of Civil Engineers have been trying to reduce the phosphorus in conformity to the increase in carbon, and I do not see why the steel companies do not meet their views and reduce the the phosphorus in the high carbon steel. It seems dangerous to leave the phosphorus the same and raise the carbon.

Mr. Camp: Mr. Finley asked in regard to the open-hearth process. It is a fact that rail metal has deteriorated chemically. Twenty years ago the phosphorus limit was 8 points; it has gradually gone up and now it is 10 points and above. I recently saw a record of analysis of some rails having 11½ points of phosphorus. There were a large quantity of rails in use on one of the trans-continental roads, and I believe it is now quite general that the rails go as high as 10 points in phosphorus.

The reason why the mills do not reduce the phosphorus is because it is in the ore, and because the rails are made by the acid Bessemer process. In order to remove phosphorus it must be made by the basic method, and in this country the basic method is worked only in connection with the open-hearth process. With the open-hearth process it is much easier to work steel by the basic method than is the case with the Bessemer process. By the basic method all of the phosphorus can be taken out of the iron, if desired, and it actually is taken down to about 5 points. A little remaining is desirable. As the phosphorus is increased the carbon must be decreased in order to avoid brittle steel. If there is high phosphorus there cannot be high carbon and still have a tough metal. One reason why steel is

so brittle these days is because it has too much of both phosphorus and carbon.

In 1896 Mr. E. H. McHenry of the Northern Pacific Ry. laid some basic open-hearth rails alternately with Bessemer rails. At the end of a year they were taken up and weighed and it was found that the wear on the open-hearth rails was only about one third of what it was with the Bessemer rails. Soon after that Mr. McHenry left the Northern Pacific and since then I have not seen any further reports on the experiment. The idea in bringing forward the open-hearth process just now is to improve the chemical composition of the steel. That is not the whole question, however; the working of the steel is fully as important as the chemical composition, and the claim in that respect at the present time is that the rails are not put through the rolls as many times as formerly; and that they are put through several hundred degrees hotter than before. There is a certain point, about 1300 degrees Fahrenheit, which is known as the critical point of steel. The closer to that point the work is done the better the results. If you get below that, the metal is too cold and you get inferior results. The 60-lb. rails laid twenty years ago were finished at a temperature of 1400 to 1500 degrees, while at the present time the finishing temperature is sometimes 1750 or 1800 degrees, and generally not much below that.

Mr. F. A. Delano, M.W.S.E. (by letter): Mr. Schaub's paper shows very clearly some of the conditions which rails have to meet in track service, and points out that, with unequal support, due to frozen track or the unequal bearing of ties in the ballast, it actually throws a greater strain on heavy rails of high section than on lighter sections of rail; in other words, the low, light section rails, being more easily deflected, adapt themselves to the bearing of the track without being overstrained. Thus, as Mr. Schaub points out, the fiber stresses to which the heavy sections of rail are subjected under these service conditions, are greater than with the lighter and more flexible sections.

Mr. Schaub's suggestions for curing the difficulty are very interesting, but of course remain still to be tried out and demonstrated. From the discussion which there has already been upon the subject in the newspapers and elsewhere, it seems quite evident that there is a danger that we shall jump at conclusions, which, like all hasty conclusions gathered from insufficient data, may lead us in the wrong direction, from which we shall at some future day have to retrace our steps.

Now that the public press has taken up this technical subject and has attempted to deal with it in a manner which shall be intelligible to the average reader, there seems to be a disposition to array the railroads against the steel manufacturers in an effort to place the blame on one or the other. Evidently, the problem must be studied sanely and quietly to determine the proper solution. Some of the remedies that have been suggested might be effective, but are so un-

reasonable in respect to expense that they cannot be seriously considered.

My study of this question dates back twenty years, and I may therefore be pardoned for expressing somewhat definite and positive opinions. The principal causes for the breakage of rails, as well as their insufficient wear, appear to be:

First: The chemical composition of the material not as good as it should be;

Second: The rolling and finishing of rails at an excessive temperature; and in this is included what is known by steel makers technically as the "heat treatment," in which connection it should be borne in mind that this matter of heat treatment becomes very much more important in the case of high carbon steel than in the case of low carbon steel;

Third: An insufficient discard from the top end of the ingot, which results in about one out of every five rails having "pipes" and accompanying segregation of impurities concealed in it.

Of these three causes I believe that the second and third are the most serious, but I shall take them up in the order mentioned.

I. *Chemical Composition of the Material.*

The acid Bessemer steel process furnishes today just as good rail as it furnished twenty or thirty years ago. While it is true that certain ores are used in the acid Bessemer process today which were formerly considered too high in phosphorus to use, and were therefore discarded, still, the blast furnace pactice of today and the Bessemer process of conversion have been so far refined that the results are much more uniform than formerly. In the days of the old John Bown Sheffield steel, it was not uncommon to find rails varying all the way from .06 per cent to .15 per cent in phosphorus. Today, we would find the average quite as high, but the variation undoubtedly less.

The basic open hearth process is rapidly taking the place of the acid Bessemer process, not so much because it is a better process, but it is adaptable to the use of non-Bessemer ores, and ore which are freuently much cheapear than the Bessemer grades. Ore which is suitable for the acid Bessemer process is not suitable for the basic process, and *vice versa*. The basic open hearth process has also some other great advantages. It is very flexible, in that it is possible to use a very large variety of raw material. It is capable of producing a very high grade material, but its use will not be a guarantee of good product.

II. *The Rolling and Finishing of Rails at an Excessive Temperature.*

In what has already been said and written on the subject, a good deal of stress has been laid on the slower rolling and colder finishing of rails. This does not mean cold rolling in the sense that it is used for cold rolled shafting, but refers to rolling at such temperature as will have an important solidifying effect on the material. It is almost obvious that an ingot entering the rolls at a white heat and rapidly

rolled in eighteen to twenty passes, into a finished rail, having a temperature of perhaps 1700° Fahrenheit, makes the material, especially in the head of the rail where the mass of metal is less exposed to cooling effects, coarse and granular; and the fracture of one of the larger sections of rail as compared with the fracture of one of the smaller sections of rail, shows without the need of a microscope, the coarser grain of the material; material which will wear more rapidly than if it had been rolled at a lower temperature. A tensile test from a sample of this rail which will show an ultimate strength of 90,000 to 100,000 pounds per square inch with a very small reduction in area and elongation, will, if rolled out into a rod, show a tensile strength of 150,000 pounds per square inch and considerable elongation; and if drawn out into a wire, will show a tensile strength of 200,000 pounds per square inch and a still greater elongation. In fact, manufacturers of agricultural implements and the like, are glad to purchase worn out rails and cut them up into short lengths, rolling or forging the metal out into various shapes; and under this sort of treatment producing a material of wonderful strength and toughness.

Nor is it certain that the remedy lies in a demand that the rail should receive more passes. In forging a piece of steel, the forging may be really more effective under a heavy, long stroke steam hammer delivering a few blows, than under a light, short stroke hammer delivering many blows; and a hydraulic press which is able to accomplish the forging operation in a single squeeze, gives results which are equal to the best. What seems to be needed to get good results is slower rolling with large diameter rolls driven by powerful machinery, resulting in finishing the rails at more moderate temperatures than has heretofore been generally practiced.

III. *Insufficient Discard from Top End of Ingot.*

In every ingot or steel casting there is a *contraction* cavity which cannot be done away with so long as the casting is cooled from the outside inward. The structure of steel thus cast is very similar to that of artificial ice, the columnar crystallization of which is familiar to every one. As in the case of water in forming ice, fluid steel solidifies from the outside inward, leaving a cavity at the center and a well marked "core."

Various plans have been devised and put into actual use in this country and abroad to cure this trouble. These processes are all pretty expensive and involve in most cases keeping the upper part of the ingot in a molten condition, so that the contraction cavity (and the consequent segregation of impurities, due, as I infer, to the lower melting point of the steel containing these impurities) will be automatically filled.

Another way of curing the trouble, of course, is to discard a sufficient amount from the ingot to remove this contraction cavity and the segregation, and in some classes of steel castings, it is not uncommon to have a "sink-head" of twenty-five to forty per cent which is discarded and remelted. The suggestion that twenty-five to forty

per cent of the rail ingot should be discarded would certainly be so radical, and would add so much to the cost of manufacture, that it is undoubtedly for the Engineers of the railways and the Engineers of the manufacturers to get together and determine whether there is not some effective and much cheaper way of accomplishing the same object. After a good deal of thought on this subject, I am convinced that there is.

Perhaps the most serious objection now to the "pipe" and the segregation of impurities, which causes hard or brittle spots in the rail, is that these impurities are entirely concealed within the rail where no inspector can discover them, and where they do not develop except in service. A method of rolling which would divide the ingot or possibly quarter it, and thereby bring this inside portion of the ingot to the surface where it shall receive the beneficial effects of the forging, and where flaws or defects could be readily detected, would, it seems to me, be a step in the right direction.

Rails are subject to very serious strains in service. As has been pointed out by Mr. Schaub, the rail has to perform several functions: It must be hard enough and tough enough to withstand the rolling and abrading effect of the wheels and flanges; it must also act as a continuous girder to carry very great loads moving at high speeds over the girder while supported on an unequally yielding foundation. It has also been clearly shown that under the wave motion of the rail beneath and in advance of trains, the rail is subject to alternate stresses of tension and compression. Perhaps the surprising thing is that the rail can be expected to do as much as it does.

From the rail maker's standpoint, this subject is a very important one, for it would be a bad thing for him if the railroad Engineers make specifications and requirements which shall eventually prove ineffective, or over-expensive and therefore react upon him. On the other hand, the railroad Engineer is sorely perplexed; he is responsible to the public for the safe condition of the track, and he is at a loss what to do. It is a fact today that the Engineers of most roads are afraid to recommend the use of the heavy section rails, because they feel that there is actually more risk in their use than there is in the use of lighter rails. In other words, that while the one hundred pound rail is very much stiffer than the eighty pound or the sixty pound rail, it is subject to higher fiber stresses, while the material itself is actually less well able to stand those greater stresses.

Mr. Schaub: A short time ago I had occasion to get some pipe. It was made by the National Tube Co. It was most beautiful metal, and when I investigated it, I found it was Bessemer steel and they told me they used Bessemer steel very largely in making boiler tubes. Bessemer steel is not bad if you make it the right way. In Germany today, if you buy bridge material the chances are you get Bessemer steel, but they use the basic process, (whereas we use the acid process), and that is the radical difference between the Bessemer steel there and here.

Mr. Field: I recently looked over some old analyses made in 1892 or 1893, where the phosphorus showed 15 points.

Mr. Schaub: I know of rails rolled fifteen years ago containing that much phosphorus, but the carbon only ran from 30 to 35 points; today it runs up to nearly 60 points. If we can get together on these analyses I think there will be no trouble whatever about the Bessemer steel.

It seems to me that the specifications for chemical requirements should specify the carbon and phosphorus in the rail, and that is all.

Is it not a fact that in our low carbon steel used in making wrought pipe, you have got to have a certain amount of phosphorus in the pipe, so the phosphorus is not such a great bug bear, if it is intelligently used. As a matter of fact, it is necessary to have *some* phosphorus in the steel.

Mr. Field: I agree with Mr. Delano that if the railroad engineers and steel engineers will get together and settle down and go back, if you choose, and start over and work up on this carbon proposition again, or begin where they are now and go down gradually until they find something that will meet the requirements, some satisfactory results may be obtained, but until it is actually tried we shall be none the wiser.

Mr. Delano: A way it was done at the Cambria Steel Works was they used the acid Bessemer process. They used to introduce a certain amount of washed pig metal to reduce the phosphorus. In this way they could get their phosphorus about where they wanted it—7, 8, or 9 hundredths per cent.

Mr. Field: The basic Bessemer process has never been a success in this country.

Mr. Schaub: Why cannot it be accomplished in this country?

Mr. Camp: It is too expensive.

Mr. Field: It would cost more than open-hearth and would not be as good.

Mr. Geo. B. Woodward: I will say that the C. M. & St. P. Ry. Co., have been making a test for the last three years of some Bessemer and open-hearth rails, and both have just worn out and no special advantage of one over the other was found. They are on very sharp curvature subjected to very severe service, and as stated above, no special advantage of one over the other was found. The tests were made at the same time under exactly the same conditions.

Mr. W. L. Cowles, M. W. S. E. (by letter): The essence of Mr. Schaub's interesting paper is an argument for an unyielding roadbed, or a construction as nearly unyielding as it is possible to secure. The advantage of such an attainment may perhaps be open to some difference of opinion. Some twenty-five years ago the writer prepared plans for a bridge over the Susquehanna River subject to the approval of the late James L. Randolph, then Chief Engineer of the Baltimore & Ohio Railroad, and one point that he insisted upon was the insertion of a substantial layer of wood between the masonry and

the steel shoe in order to provide a certain amount of elasticity and thus reduce the effect of impact. The bridge was not built at that time and this detail was not, to the writer's knowledge, adopted in that structure although it is his impression that it had been used on earlier bridges on that road. It illustrates, however, the prevalent feeling that, until rails can be laid with the surface absolutely perfect, a certain amount of elasticity is desirable.

The result of a low joint would be as indicated by the author, a severe bending of the rail near its end, the extreme fibre stress being greater in a heavy rail than in a light one for a given depression, if the conditions assumed in his discussion were met with in practice. These conditions are that the tie under the joint is permitted to yield a definite amount to an unyielding point and that the adjoining ties are unyieldingly supported at their proper level, also that the splices give no vertical resistance to the rail's deflection. These conditions will never be met with on a good roadbed, and if they exist at any point, it is a matter for the section gang to attend to rather than the rail maker.

The best roadbed has some compressibility and under a heavy load suddenly applied will surely yield to a degree, producing the wave like motion mentioned by the author, and the rail will be in the condition of a continuous girder supported on slightly yielding supports and loaded by a rapidly changing series of unequal loads—a set of conditions baffling exact analysis.

If the roadbed offers uniform resistance at all points the bending effect on the rail will be constant over its entire length and its amount and the resulting fibre stress will be a combined function of the moment of resistance of the rail and the compressibility of the roadbed and tie.

An exception to this occurs at the joints where the moment of resistance is only that of the splices and where consequently the pressure on the tie is greater. The tendency of this increased pressure is, of cource, to disintegrate the roadbed more rapidly, calling for special attention of the section gang to these points. There is no other reason why the road bed at the joints should offer less resistance than at other points, indeed, the special attention called for may keep it in better condition, resulting in "hard spots."

Even if there should be "soft spots" at the joints the additional pressure at these points is only that due to the difference between the amount of resistance of the rail and that of the splices and unless this should deflect the rail to a point of absolute refusal, which would be the same for either a light or heavy rail, the fibre stress would be less for the heavier rail.

It is therefore the opinion of the writer that heavy rail is not a source of danger due to excessive fibre stress from deflection at the joints, but is demanded by heavier loads in order to better distribute the load, thereby diminishing the destructive effect at these joints and the consequent deflection.

Mr. Edgar French, M.W.S.E. (by letter): Careful investigation must show that the solution of the track problem does not lie in the increased weight of rail, and until a better joint fastening is devised, no relief need be expected from a rail weighing more than 80 lbs. per yd.

The Sampson re-inforced plate was a long step in advance of the original fish-plate.

The angle bar marked another long stride in advance of the plate, and the continuous rail joint, and similar appliances, have contributed to the further improvement of what track-men have always considered the weak point in track, namely the joint.

As Mr. Schaub says, "The breakages usually occur near the ends of the rail," and it seems reasonable that the remedy, if there is one, should be applied at the point where the defect is found to exist.

All who have had to do with track renewals under heavy traffic, have noticed the imperfect contact between the rail and its fastening.

On the upper edge of the fastening, and on the lower edge of the ball of the rail, will be found two or three bright spots indicating contact, while the balance of the supposed bearing surface is innocent of any contact whatever.

Planing the bearing surfaces would not cure all joint evils, but it would greatly increase the efficiency of the fastenings now in general use, and the only objection urged against it so far as I know, is the small additional cost.

The Railway Companies have been purchasing 90 and 100 lb. rails, apparently believing that such expenditure would result in greater safety, and reduced cost of maintenance.

The results have not been satisfactory, as shown by recent investigations of rail failures, and while it may be possible to manufacture heavy rails of good quality it has not been the practice to do so.

When these investigations have been carried to their ultimate conclusion, it is to be expected that about 80 lbs. will be the section adopted for general use, with reasonable appropriations for ties, ballast, and drainage, and special attention to fastenings.

The proposed arrangement of track on longitudinal girders will hardly meet with favor, but Mr. Schaub's treatment of the track and rail question is interesting, the topic is timely, and its discussion should result in much good.

Mr. H. J. Slifer, M.W.S.E. (by letter): Mr. J. W. Schaub's paper: "The Railway Track of the Past and its Possible Development in the Future," is timely, important and interesting; but its scope is of such a character that the owners of the properties will have to be educated to the importance and necessity of abandoning the use of the present form of track and adopting one which will cost much more for its original construction, but which will be much less expensive for maintenance.

We frequently hear of the term "permanent way" but outside of some few exceptions, the railway tracks of the United States are

practically built today along the same lines that were adopted when the pioneer track was laid. In fact, there is some question in the writer's mind as to whether we have not made "crab" progress, and we have certainly not done anything, except to make our ties, rails and joints heavier.

One of the most important adjuncts to good track is the spike, which is about the same as originally used, and very few of the improvements and modifications, such as the wood screw, have been adopted as standard.

How many of us have watched a track laborer drive a spike into a well-seasoned hard wood tie, and been compelled to note in disgust the abuse which both the spike and tie were receiving?

The quotation from Mr. O. E. Selby's paper is very apt and particularly so when we compare the technically improved designs of the Mechanical Department with the neglected attention given the Track Department.

The author has plainly shown that the original form of track, along the line of continuous longitudinal support is one which should have been developed, in place of the one now in use, which entails "eternal vigilance" and creates enormous expenditures.

Don't blame the railroad manager if your track is not securing its share of attention, but rather look to the Board of Directors, who have been educated to believe that the first place to curtail expenditures, both improvement and renewals, is in the repairs of track.

Have we, as members of the engineering profession, been persistent in our advocacy for improvements of a permanent nature, or have we been satisfied with a heavier tie and rail?

The question of a "permanent way" is a very old one, but is a live one every day, and we, as members of the profession, must expect to advocate it, as we are afforded the opportunity.

In the "Railway Critic" (Vol. 6 No. 66, pp. 262 and 263) under date of June, 1907, inquiries are made for a design of roadbed and track which will dispense with cross-ties and ballast.

Longitudinal timber stringers on concrete roadbed are advocated, and it is claimed that such construction will do many things that should be favored by every department of the railway organization. The passenger department could advertise "easier riding track, adding to the safety and comfort of the passengers." The mechanical department could "reduce repairs on rolling stock and lessen the power to haul trains." The maintenance of way department would be able to almost "eliminate maintenance and renewals."

We can understand that the manager would welcome this condition: but where are the directors to secure the finances to bring it about? However, that is not an engineering question, but we can not escape the knowledge that until the present adverse agitation, both State and Federal, is quieted, we as Engineers will receive but little encouragement from the Board of Directors and owners. This

need not deter us from discussing the improvements with the view of adopting uniform recommendations.

The Author should have the hearty support and encourgaement of every member of the profession in his advocacy of an "absolutely unyielding substructure" and if any elasticity is required, it can be taken care of in the design of the equipment, where it properly belongs.

In each of the designs shown in the Author's paper, it is noticed that timber in one form or another is made use of, although the Author's final arrangement will eliminate its use entirely.

We certainly cannot consider the use of timber very much longer, and even today the railroads are unable to secure what they require for renewals alone. If our forests could produce the necessary amount of timber for all purposes, there would possibly be economical reasons why it might be used for the ordinary railway track, but such construction would not be permanent nor would it eliminate renewal charges.

For subway tunnel construction, the use of timber for any and all purposes should be prohibited by law, and any one who is compelled to ride in an atmosphere of decaying timber will support the views of the New York City Club, who, in July, 1907, reported to the Public Service Commission that "in the interest of good sanitation, the tube should have concrete floors." Why not go a step further and eliminate the use of timber? The plans for the Philadelphia subway show two kinds of construction, and in one of them, no timber is used. It will, therefore, be seen that we are progressing, and all future subways should be constructed so as to avoid the use of any and all timber.

The writer has for some years advocated an "absolutely imperishable and unyielding" construction of both substructure and superstructure, and is pleased to endorse the Author's views along said lines.

Mr. G. H. Blakely, Bethlehem Steel Co. (by letter): The paper by Mr. J. W. Schaub on "The Railway Track of the Past and its Possible Development in the Future" has attracted considerable attention among railway men and among those who are making a study of improved track construction. In this paper Mr. Schaub discusses the Lindenthal experimental track on the Pennsylvania Railroad and says the experience with it is exactly as should be expected and that it is impossible to keep such a track in surface. Mr. Gustav Lindenthal, the designer of this track, in a letter from him appearing in Engineering News of June 20th, takes issue with this statement and after explaining some of the troubles which developed in the initial stage of the experiment, which have since been corrected, says the track is now keeping perfect surface and that no wave in front of the wheels is observable.

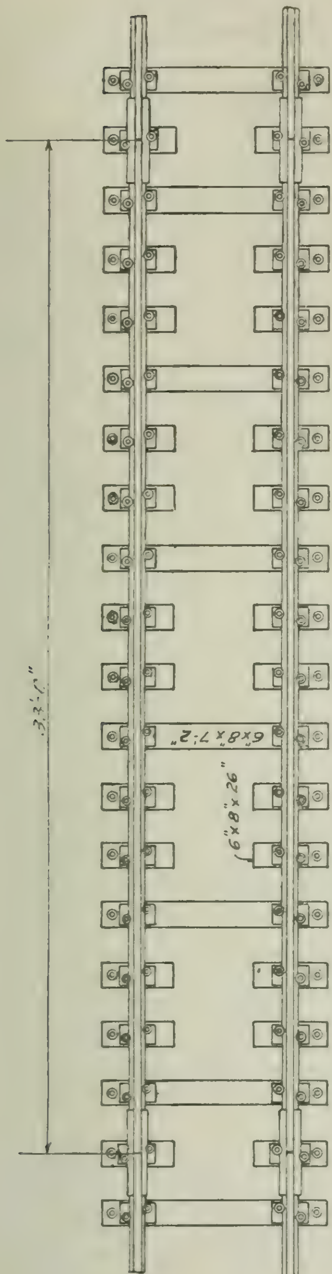
Believing that the use of longitudinal steel sleepers in combination with cross ties or otherwise may offer a solution of the problem

of securing the much desired improvement in track construction for heavy traffic conditions, and in view of the conflicting opinions regarding this track the writer made a personal examination of its condition observing its action under the passage of trains.

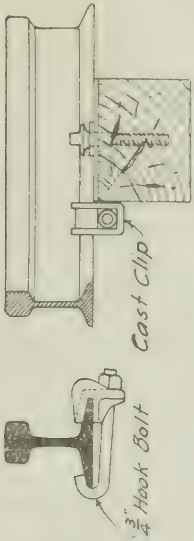
This experimental track, about 1,000 feet in length, is on the east bound freight track on a descending grade of about 30 feet to the mile. Originally the rails were supported by cast iron chairs which were bolted to the longitudinal steel sleepers. Creeping of the rails took place to such an extent that the chairs were tilted. These chairs were removed and replaced with wood ties and blocks sawed to dimension and secured to the longitudinal sleepers with hook bolts. The ties which act as spreaders are spaced six (6) feet on centers. Between the ties the rails are supported on short timber blocks spaced two (2) feet on centers. The rail joints are supported on similar blocks with a spreader tie at each side of the joint. (Fig. 1.) It was intended that each longitudinal sleeper should be made of a pair of 8 in. by 9 in. bulb angles riveted together with separators at intervals but as no such sections were rolled by the mills the equivalent of each bulb angle was provided by riveting a 7 in. by 3 in. bulb angle to a 8 in. by 3 in. "Z" bar (Fig. 2). To counteract creeping of th rails, cast clips bearing against the ties are hook bolted to the rails (Fig. 3). In the original design it was the intention to use rock ballast only under each rail and to fill in between the rails with sand or gravel, but as constructed no sand or gravel seems to have been used and the rock ballast extends the full width of the roadbed. It could not be determined if a drainage system had been provided for the sub-surfaces. The foregoing is a description of the track as actually constructed and which differs in some respects from the drawings of it previously published.

Passing now to the present condition of the track, it is considerably out of surface but in this respect it is not much more out of surface than the west bound freight track. The impression was formed after inquiry at the main office of the railroad company, that the maintenance of this track was expensive but that the experiment had not been continued a sufficient length of time to make a definite statement. From inquiry made at the site it would appear that the longitudinal sleeper system has not received attention since it was laid. Considerable expense has been incurred in changing from the iron chair system to the present wood tie and block system, but outside of this, the ballasting of the track has not received any attention since it was laid nor has any attention been given to correcting the alignment of the rails since the iron chairs were removed.

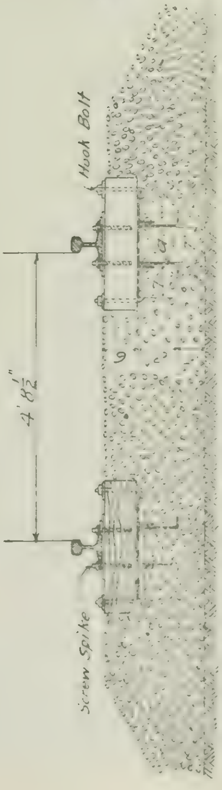
Although the rail joints are supported on the wood blocks yet low joints have developed by the crushing of the tie plates into the wood. Such low joints are especially marked at the easterly end of the track and occur in such a way that the worst cases might be accounted for if the rail joints nearly coincided with joints in the



Plan.
FIG. 1.



Creeper Clip.
FIG. 3.



Cross Section
FIG. 2

sleepers. The sleepers are in lengths of 33 feet and if 30 ft. rails were used coincidence of joints would occur at intervals, or the same result would be due to the use of a short length of rail. It is impossible to determine this from a superficial examination as the sleepers are buried in the ballast and the joints in them cannot be seen, though one short length rail was noticed in the track.

A very pronounced wave movement is observed under the passage of a train. The vertical movement of the rails in general is $\frac{1}{4}$ inch and in some particularly bad spots is as much as $\frac{3}{8}$ inch or more. This wave movement occurs to a considerable extent in the steel longitudinals and the projecting flanges of the "Z" bars communicate the movement to the upper layer of the ballast which is raised and lowered with the movement of the track. The wave motion of this track under a freight train at 20 miles an hour is much more pronounced than it is on the adjacent passenger track of standard construction under express trains at high speed.

The creeping of the rails seems to have been checked by the creeper clips which have been used for that purpose. There is no evidence of the rails having slipped through the clamps and the ties do not show that they have been pushed forward by movement of the rails. Creeping of the rails in this case seems to be an incident of location and grade and not due to the form of track. Creeper clips are used on the same track for a distance of nearly half a mile west of this experimental construction.

The preceding aims to be an impartial statement of the condition of the track as it exists and of its action in service. The remarks which follow are called forth by a study of this track and are offered, not as recommendations, but as suggestions for the improvement of this type of track construction.

Suspended rail joints with angle splices having webs projecting below the rail flanges would seem to offer a more satisfactory splice than the supported joint which is used. The experiment seems to demonstrate that a single tie, even if solidly supported, is insufficient to resist the crushing effect at the ends of the rails due to their deflection.

If the tie plates had rolled bevel ridges parallel to the rail and washers having a corresponding bevel were used under the heads of the screw spikes, the washers fitting close against the rail flanges, the ease of aligning the track would be increased (Fig. 4). This idea is suggested by the Hohenegger longitudinal system used by the Austrian State Railways where a similar device is employed for clamping the rails.

The vertical movement of this track under the passage of trains indicates that it does not provide enough bearing surface on the ballast and that the longitudinals have inadequate vertical stiffness for distributing the concentrated loads over sufficient distance to give satisfactory results. In both of these respects it is possible that the design of the longitudinal sleepers might be improved so as to give

sufficient bearing surface on the ballast and provide adequate vertical stiffness.

The original design contemplated the use of special bulb angles with 8 in. legs bearing on the ballast thus providing a bearing 16 inches in width under each rail. The space between the bulb angles could not be depended upon for any distribution of the load on the ballast. As such sizes were not rolled, the sections actually used were made of available structural shapes to approximate as nearly as possible to the section which was intended. In the actual sleeper there is only 14 inches width of bearing surface on the ballast under each rail. It is impossible to secure a satisfactory tamping of the ballast in the space between the two vertical webs, and the lower projecting flanges of the "Z" bars are so narrow as to offer no bearing surface on the ballast which should be taken into account. The shape of the longitudinal sleeper is not adapted to the purpose but it seems to have been the best which could be devised using such sections as were available. The question arises if it would not be possible to devise a section for this purpose which would offer greater bearing surface and provide greater vertical strength. It is believed that it is possible to do so with a section that would cost less than the one proposed by Mr. Lindenthal.

Mr. Schaub in his paper has suggested the use of Bethlehem Steel Co. wide flange beams for a nearly similar purpose in track construction. The beam which he suggests is a 10 in. girder section, having flanges 9 in. wide and weighing 44 lb. per ft. If such a section does not seem to offer sufficient bearing surface on the ballast the width of flange might be increased. As beams of this kind are not made by means of fixed grooves cut in the rolls, but are made by the Grey Universal Mill which has horizontal and vertical rolls acting coincidently and forming the web and flange of a beam shape by combined rolling operations acting at right angles, therefore variations in the shape can be made by spreading both sets of rolls. Considerable variation in the section can be secured and the matter of expense for the change in rolls required is not a serious one, especially if the tonnage involved is considerable. To meet the demands of the case, the flanges of this beam might be increased to 10 in. in width, the depth of the beam being correspondingly increased a slight amount (Fig. 5).

It is probable that a 10 in. girder beam of this kind would be a better section for the purpose Mr. Schaub has in mind. This 10 in. section as modified gives a beam 10⅛ in. in depth, with flanges 10 in. wide, having a section modulus of 57.5 and would weigh 48.75 lb. per ft. It would offer an effective bearing surface on the ballast of 20 in. in width under each rail. The two bulb angle sections under each rail suggested by Mr. Lindenthal, would have a total section modulus of only 28.5 and would weigh 56 lb. per ft. including separators. The suggested rolled girder section weighs 13% less than the bulb angle section, and the latter requires riveting to-

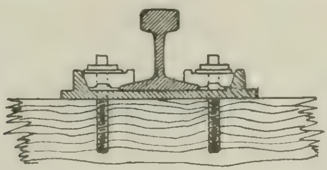
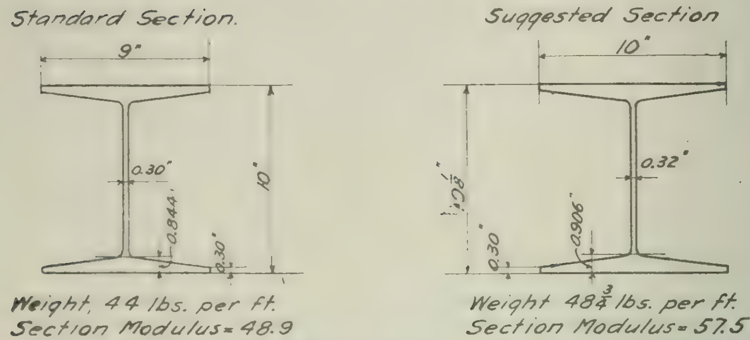


FIG. 4.



BETHLEHEM 10" GIRDER BEAM AND SUGGESTED VARIATION.

FIG. 5.

gether of the parts, the expense of which is saved in the case of the single rolled shape. The wide flange beam would therefore cost at least 20% less than the bulb angles, and at the same time it would offer an increase of 25% in effective bearing surface on the ballast and an increased vertical strength of 100% over the bulb angle sections. This comparison is drawn with the Lindenthal proposed bulb angle sections and not with the existing sections which were built up to approximate the desired bulbs. The built section actually used in this experimental track has a section modulus of 27.0 and with separators weighs 65 lbs. per ft.

It might be thought that the same purpose could be served by a shallow riveted plate girder with wide flange angles. But such is not the case as the upward pressure of the ballast, when the girder is loaded, would bend the chord angles at their roots unless they were made of such great thickness as to render the cost prohibitive. In addition such a riveted section, because of the expense of its fabrication, would cost more per unit of weight than a rolled section.

The tapered thickness of flange in the suggested rolled beam provides ample resistance to the bending produced by the pressure of the ballast. With axle loads of 60,000 lbs. spaced 5 ft. apart, after doubling all stresses to allow for impact, the suggested rolled beam section under all combinations of loading, both longitudinally and transversely, would not be subjected to stresses exceeding those

allowed in the best bridge construction. The pressure on the ballast, including 100% allowance for impact, would not exceed 3.4 tons per sq. ft., as against 4 tons usually considered allowable for this purpose. This is in contrast to the bearing of ties in the best standard contruction, which under the most favorable conditions produces a pressure on the ballast of 5.3 tons per sq. ft. when the effect of impact is considered, and which intensity of pressure explains the crushing of the ties into the ballast. With sufficient depth of ballast under the longitudinals, the pressure on the subgrade can be kept down to a maximum of 1.75 tons per sq. ft., when impact is considered, and which is an entirely safe pressure to use on well compacted clay, sand or gravel soil such as is afforded by seasoned railway embankments.

The cost of such a system would be about $12,000 a mile of single track for the longitudinals, in addition to the expense for ballast, ties and rails. Adding these items would just about double the present cost of first class standard track with rock ballast. With a saving in maintenance of $700 a mile effected by such a system, as estimated by Mr. Lindenthal, the return on the added investment would be about 6%. Moreover, with such a track the effective hauling capacity of locomotives would be increased by at least 10% which would correspondingly reduce train operating expenses a like amount. Of course such construction is not likely of consideration except for track where traffic is dense and heavy, under such conditions as prevail on some congested divisions of the great trunk line railroads. The security and safety afforded by such a track deserve consideration aside from the financial view of the matter. Present track construction is inadequate for the loads imposed by modern railroad traffic, and as the continued tendency is to increase wheel loads, for the purpose of reducing operating expenses, a radical improvement in track construction must be made to meet the situation, either in a modification of the manner indicated by this Lindenthal experiment or in some other way following the lines suggested by Mr. Schaub.

It is evident from what has been said concerning the wide flange beam shapes and their possible application in the case here discussed that the Grey mills afford a great elasticity of design in the production of such sections. The establishment of mills of this kind in the United States will afford structural steel in new forms and will undoubtedly aid the engineers of this country in successfully handling many problems which have heretofore been incapable of satisfactory solution with the usual structural sections previously available.

THE CONSTRUCTION OF SMALL PARKS IN CHICAGO

By Linn White, M.W.S.E.
Engineer South Park Commissioners.

Presented November 20, 1907.

When I was asked to prepare a paper on the construction of Small Parks in Chicago I began to think it over as to what Engineering problem there could be connected therewith of sufficient importance to present to this society. I quickly concluded that while there are various engineering questions involved each one is relatively small and none could be made of more interest than the one central idea of the Small Park itself. What is it and why should it be?

In attempting to answer this question I think it would be proper to tell something of the Boards that have charge of building and maintaining the Small Parks and the legislation that brought them into existence, as well as some of the results attained. With these ideas in view I trust you will pardon me if I wander somewhat out of the field of Engineering in pursuance of my subject.

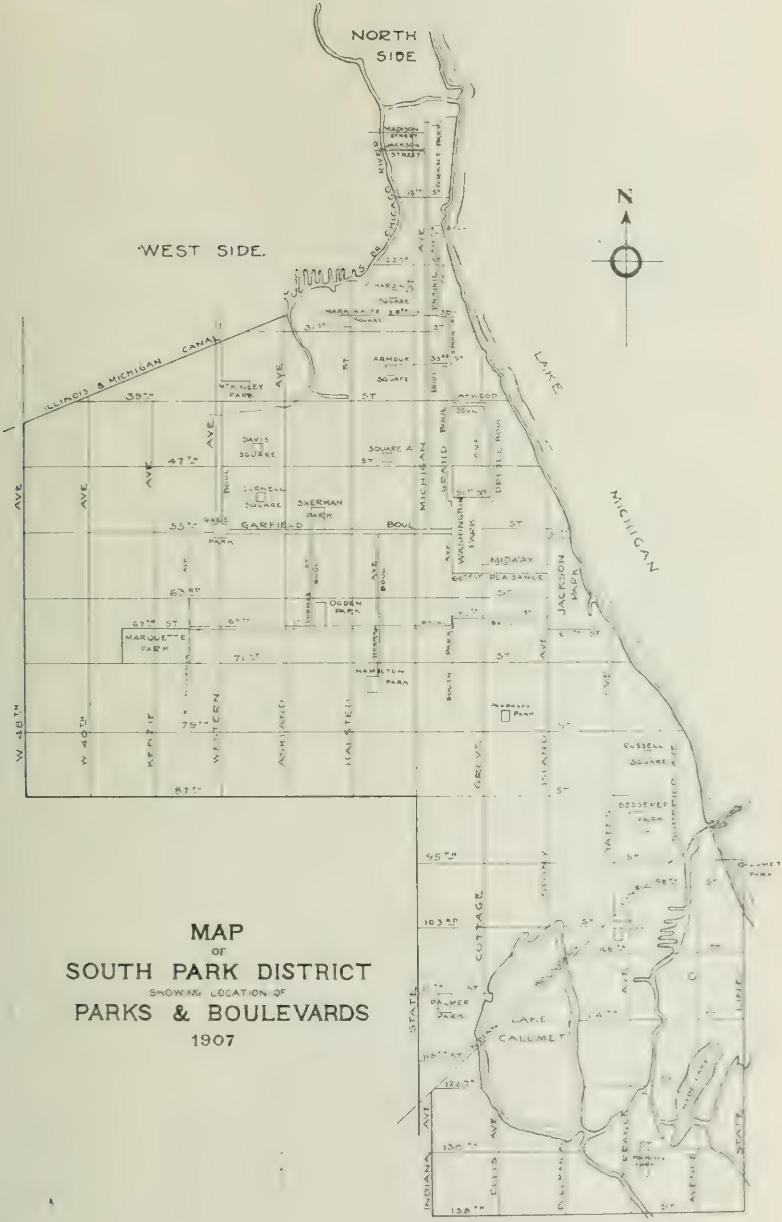
There are four public bodies in Chicago who have to do with the construction and maintenance of small parks, the Special Park Commission under direct control of the City Council, and the three independent Park Boards, viz., the West Chicago, Lincoln and South Park Boards. It is of the work of the South Park Board I shall speak, as it is the only one that has yet carried the Small Park idea to full fruition.

The Small Parks under the control of the City Commission are mainly and essentially municipal playgrounds or else little parks, improved with trees, grass, etc., to provide breathing spaces. The Small Parks which are constructed or under way by the other Park Boards mean more than this, as will be explained further on. While the South Park Board is the only one that has fully carried out the idea, the West Park Board and the Lincoln Park Board have plans under way for several Small Parks which will be finished up on similar lines to those of the South Park Board.

The district under the jurisdiction of the Board of South Park Commissioners comprise practically all the section of the city south of the Chicago River and the Illinois & Michigan Canal. It therefore extends from Water Street to 138th Street, from the lake to West 48th Avenue, an area 16 by 10 miles. The population in this district is over 600,000, and the tax valuation of property is $200,000,000 on the basis of 1/5 of the full valuation.

The revenues of the Board are derived from direct taxation and from the sale of bonds which have been issued from time to time for specific purposes. The Board consists of five members appointed by the Circuit Court, one member being appointed each year. It is, therefore practically a continuing body, and as such can lay out a

definite plan or policy which is reasonably sure of being followed from year to year.



Previous to the year 1903 there were five parks and 17.28 miles of boulevards under the control of the Board,

Jackson Park	540 acres
Washington Park	371 acres
McKinley Park	40 acres
Gage Park	20 acres
Grant	205 acres

nearly all of the latter of which was either under water or only a rough dumping ground.

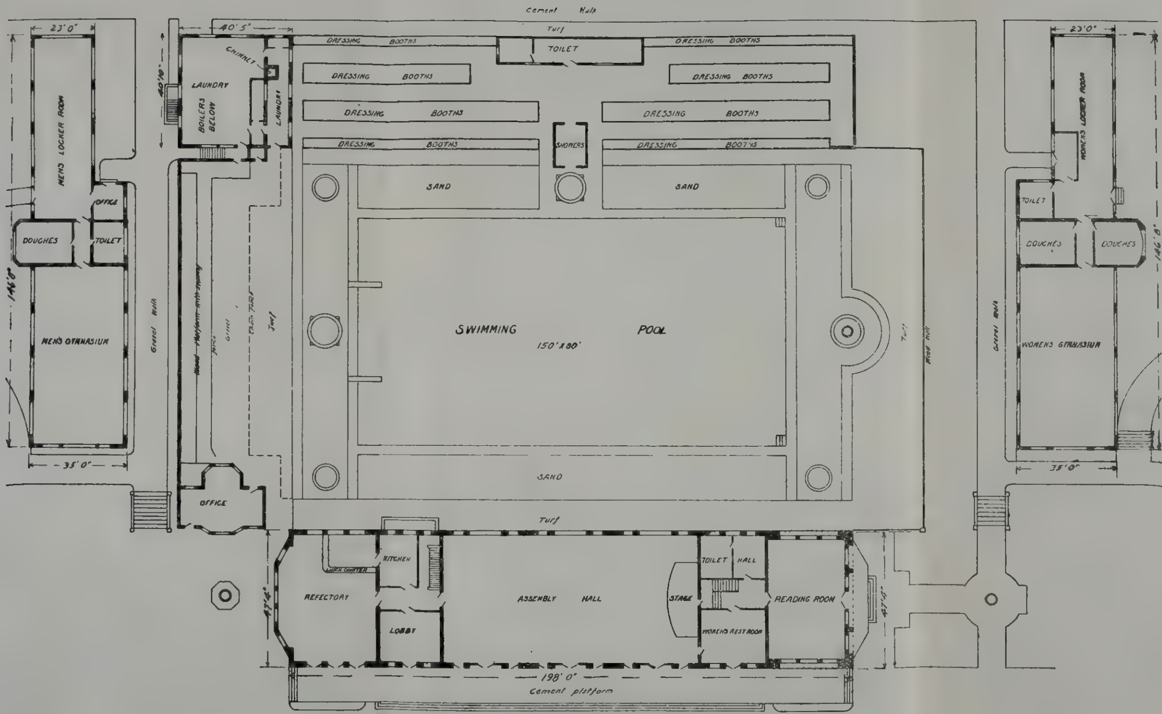
Bond issues were voted upon favorably by the voters of the South Park District, and as a result of this action the number of the parks has been increased from five to twenty-three, and the acreage from 1,356 acres to about 1,700 acres, not including Boulevard areas. Ten of the newly established Small Parks have been completed and the others are in various stages of construction. The length of boulevard under the control of the Board has been increased from 17.28 miles to 28.5 miles, with other additions probable in the near future. Other acts of Legislature have given the Board of South Park Commissioners the Riparian right along the shore of Lake Michigan from Grant Park to Jackson Park and south to 79th Street, or from Randolph Street extended to 79th Street extended, a magnificent stretch of water front 10 miles long. The result of this has been a definite plan to fill in as rapidly as possible a strip of water about a half mile wide and six miles long connecting Jackson and Grant Park. The detail plans for this have not yet been completed but surveys and soundings have been made, and it will be an outshore drive and parkway, at some places expanding to the proportions of a respectable sized park with a sheltered waterway or lagoon the whole distance spanned by occasional bridges from the mainland. The rest of the lake frontage south to 79th Street will undoubtedly be filled in some time in the future. This is all in direct line with the City Beautiful idea which has recently been much discussed in a public way. While other civic bodies are interested in a City Beautiful the South Park Board will doubtless be the first to do active work in furtherance of the new ideas, insofar as new ideas have been called forth.

It may be emphasized in passing that the various park boards have been working for years on a City Beautiful, and, so far as their policies are indicated by their works, there is to be no change. Only, perhaps, a quickening of public spirit and a strengthening of the hands of the officials charged with the execution of the wishes of the public. But it is not of this particular phase of the Park work I wish to treat.

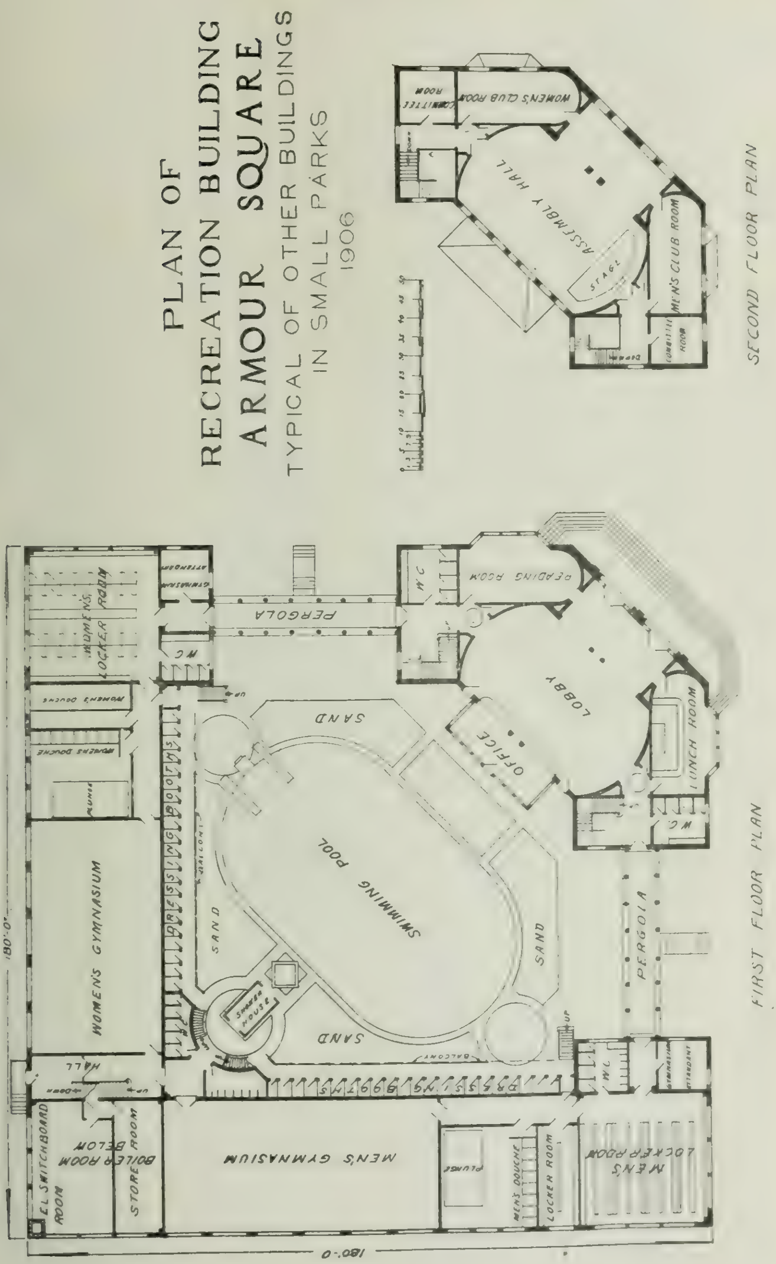
The Small Park, as developed in Chicago, combines the features of a park; a neighborhood center with assembly hall and meeting rooms for clubs and societies; a reading room with a branch of the Public Library; and a public gymnasium with swimming pools, play grounds, etc. As a number of them are ten acres or less in size the park feat-

SECOND FLOOR PLAN.

FIRST FLOOR PLAN



PLAN OF
RECREATION BUILDINGS
OGDEN PARK

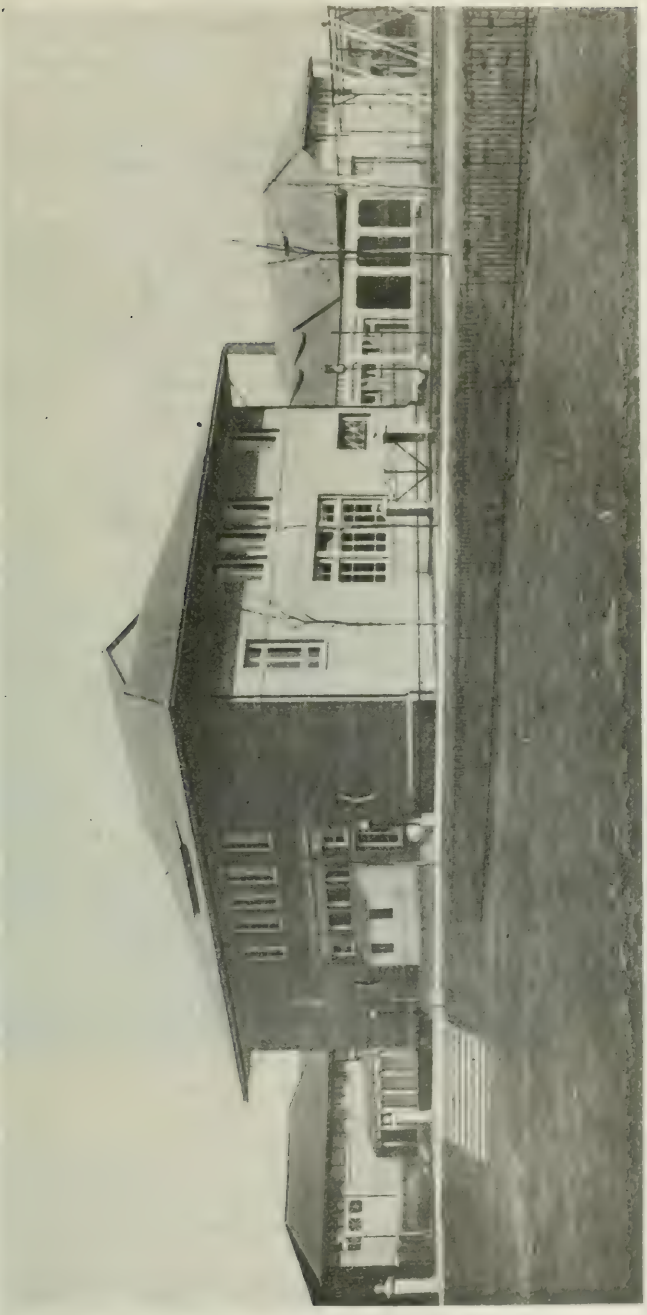

PLAN OF
RECREATION BUILDING
ARMOUR SQUARE
TYPICAL OF OTHER BUILDINGS
IN SMALL PARKS
1906
WOMEN'S CLUB ROOM
COMMITTEE ROOM
ASSEMBLY HALL
STAGE
MEN'S CLUB ROOM
SECOND FLOOR PLAN
WOMEN'S LOCKER ROOM
WOMEN'S DOUCHE
PLUNGE
WOMEN'S GYMNASIUM
HALL
EL SWITCHBOARD ROOM
BOILER ROOM BELOW
STORE ROOM
MEN'S GYMNASIUM
MEN'S DOUCHE
LOCKER ROOM
MEN'S LOCKER ROOM
DRESSING BOOTHS
SAND
SWIMMING POOL
SHOWER HOUSE
BALCONY
PERGOLA
W.C.
READING ROOM
LOBBY
OFFICE
LUNCH ROOM
FIRST FLOOR PLAN
180'-0"

ures in so small an area are necessarily restricted and somewhat subordinated to the others. Also, on account of their small size, the plans are necessarily formal, and the greatest economy of space must be exercised.

However, in some cases the area is much larger, as Palmer Park, area 30 A., and Sherman Park, area 60 A., where the freedom and variety of design suitable to larger park areas has been employed. One end of it, however, has been laid out on formal lines with a symmetrical group of buildings, as in the smaller parks, comprising Assembly Hall, Reading Room, Gymnasium, etc.

The general idea of arrangement of all the groups of Park buildings is to have an open air swimming pool in a central court with the gymnasiums and Assembly Hall building, or Field House, grouped around. Typical of these is Armour Square, ten acres in size, where economy of space is obtained by putting the Assembly hall on the second floor, the whole group of buildings occupying a space in one corner of the park, 180 ft. by 180 ft.; also Ogden Park, 60 acres in size, where the buildings form a rectangle 380 ft. by 240 ft. with the assembly hall on the ground floor. Some special features of design of these buildings will be described later on.

One of the new park sites acquired by the South Park Commissioners, Marquette Park, at 69th St. and Kedzie Ave., contains 322 acres, which makes it about third in size of any in the district. The plans in this park include all the features of the others and while it cannot be strictly called a small park it is one in the sense that it carries out to the fullest the small park idea. Here are to be swimming pools, spacious gymnasiums, an outdoor athletic field, running track, etc., on a scale impossible in the small areas. In addition there will be golf links, broken wooded areas and an artificial lake 50 acres in extent. In the excavation of this lake there will be, in round numbers, 1,000,000 cu. yds. of material moved which will be used to build up knolls and hillocks out of what was a dead level. The grading of 60 acres, or about one-fifth of the area of this park, will be completed during 1907. The excavation is being made by steam shovel and distributed over the filled area by tram cars. The depth of cut, which is entirely within the Lagoon area, is about 12 ft. and the fill is from nothing to 13 ft. Handling such an excavation and fill with steam shovel and tram cars presents some peculiar difficulties the railroad steam shovel man does not have to contend with. Much of the cut has to be handled in two lifts because the excavated areas are restricted and irregular in outline so it is not practical to haul the loaded cars up the necessarily heavy and short grades out of the pit, and the lift of the shovel is not enough to load cars standing on the surface grade. Again, the unloading track is a difficult proposition to handle where the fill varies from one to thirteen feet and where, instead of having a level or even grade to work to, it is made purposely irregular. Under these conditions something over 1,000 cu. yd. cars have been handled in eight hours with a



Concrete Construction, Cornell Square.

shovel with a 1½ yard dipper. The average, however, is considerably less than this. The average cost has been 30 cents. The problem is to handle the cars and return them to the shovel—not to load them.

The grading of a small park has been generally either a very simple matter or a serious problem according to situation or elevation of surface. Some of those constructed by the South Park Board have been planned to balance exactly in cut and fill. Examples of these are Russell Square, 83rd St. and Bond Ave.; Hamilton Park, 73rd St. and Normal Ave.; Cornell Square, 51st and Wood Streets. In most of these, as in Cornell, the central area is depressed below the general level and used for a ball field in the summer and a skating pond in the winter. Others, as Armour Square, 33rd St. and Shields Ave., and Hardin Square, 25th St. and Wentworth Avenue, are close enough to the business areas to get a large proportion of the necessary fill from building excavations. All that was necessary in these cases was to clear buildings away, stake out the desired grades, let it be known here was a free dumping ground and put an inspector in charge. Sherman Park, 55th St. and Centre Ave., had a surplus of

Field House in Sherman Park.

30,000 cu. yds., while Ogden Park, one mile south, had a corresponding deficit. Cuts and fills in these two places were balanced, a steam shovel was put to work in Sherman, a narrow gauge track laid along Loomis Street from one to the other, and the 30,000 cu. yds. transferred to Ogden Park.

Bessemer Park, 27 acres in size, at 89th St. and South Chicago Avenue, was located in a swampy region beyond the reach of ex-

isting sewers and 153,000 cu. yds. of sand fill and 20,000 cu. yds. of top soil were brought in over a standard gauge track laid for the purpose, raising the level from 2 to 6 ft. The cost of the sand filling was 44 cents and the top soil 78 cents per cu. yd. In nearly all the new parks built it has been necessary to purchase the top soil for lawn and planting spaces, either wholly or in part, the original soil having been removed or rendered unfit for cultivation. The question of a proper soil and the proper care of an originally good soil is one that received serious consideration in park work. It is difficult in the best of soils to grow good trees and grass where smoke and dust dry up the foliage and gas leakage poisons the roots. As to what damage these enemies of growing things can do we have but to look at Michigan Avenue north of 35th St. and the strip of park land between Michigan Avenue and the Ill. Central R. R. Where we would most desire noble trees and luxuriant foliage there is none.

In the effort to ward off the evil of gas leakage, concrete curbing five feet deep has been built around all the new parks located in the populous districts. Just how much good this will do remains to be

Reinforced Concrete Bridge, Sherman Park

seen. The hope of the future for foliage in the small parks scattered through the industrial districts of Chicago lies in the curbing of the smoke nuisance and the electrification of the railways. A park without thriving trees is a misnomer and a playground without grass and foliage is but one step removed from the street.

Some details of design and construction are as follows: Drainage and water supply are, of course, essential requirements for

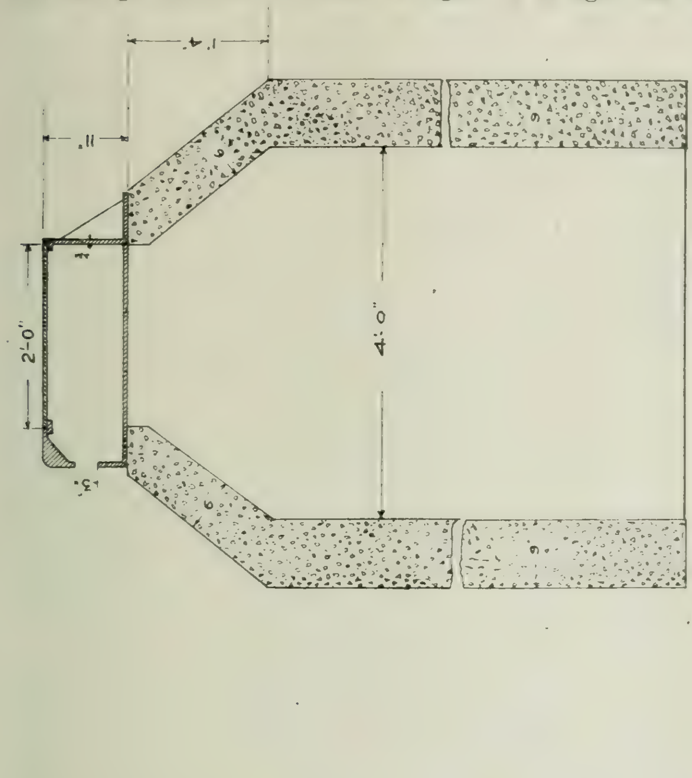
any park, great or small. Neither of these present any special difficulty in the construction of our small parks, but a few words as to the standards used will not be amiss. One 6 in. main serves as a supply to most of the smaller 10 acre parks, while Ogden, a 60 acre park, has four 6 in. connections with the 30 in. city main crossing it. Others are supplied in like proportion. A system of from 6 to 2 in. pipes distributes the water to swimming pools, fountains, buildings, shower baths, toilet rooms, lawn hydrants, etc., the latter of which are located so that with 100 ft. of hose every foot of the park area can be reached. No wrought pipe is used for water distribution, only cast iron or lead, on account of the rapid corrosion of wrought pipe laid in the soil. The 2 in. cast iron pipe has generally been of the Universal pattern, the joints turned to a close fit and made fast with projecting lugs and bolts. Most of the pipe larger than 2 in. is of the regular hub and spigot pattern with caulked lead joints. Each lawn hydrant is attached to the iron pipe by a short section of 1 in. lead pipe, and it has been found economical, where the branch is 25 ft. or less in length, to make it all lead, instead of laying the necessary specials to run the iron pipe branch. The sewers are all of vitrified clay pipe, connecting with the city sewers.

In two parks, Bessemer, 89th St. and South Chicago Ave., and Russell, 83rd St. and Bond Ave., no city sewers were available at the time the parks were constructed and temporary pumps were put in, discharging into the nearest ditch. Of these the one at Russell Square has been discontinued as the new city sewer has reached the neighborhood, and the one at Bessemer Park will be within a few months. Catch-basins are placed in pairs about 150 ft. apart, or less, where circumstances require, along drives and walks. Most of them have been made of concrete of the designs shown, the smaller one for walks and the larger for drives. The walk basins are cast in the moulding room, in sheet iron moulds, at a cost of about $3.00 each, exclusive of frame and grate which adds about 75 cents more. The drive basins and manholes of the same pattern are built in place without an outside form, if in clay, but if in sand, a sheet metal form or ring is used which is lifted as the concrete is placed and back-filled. The inside forms are either of wood or steel, built in sections and collapsible. If of wood the cone is separate from the drum, but in a new design of steel form we have recently designed the cone and drum is made in one piece. The cost of the concrete drive catch basins is $12.00 against $20.00 if built out of brick.

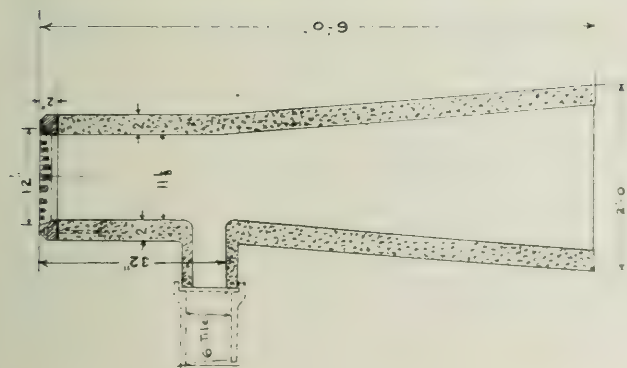
The outlet from walk basins is of 6 in. and from drive basins of 9 in. pipe. Seldom are any of the connections trapped, as but few of the park sewers receive anything but surface water.

The lighting of all the older parks and boulevards is done from the generating station in Washington Park which is now being rebuilt and refitted with turbo-generators of the latest type, of a capacity to light all the new parks in the system. High tension circuits laid in conduits lead from the power house to a distributing point in each

park building where the transformers and regulating instruments are located. The arc lamps for outdoor lighting are of the Fort Wayne enclosed type. An average of 50 are used in each 10 acre park. The posts are of cast iron, with moulded concrete base, are 12 ft. high from the ground line to center of light, of as light and simple a



Cross Section of Drive Catch Basin



Cross Section of Walk Catch Basin

Concrete Construction.

design as is consistent with necessary strength. The lighting is sufficient for the use of swimming pools and outdoor gymnasiums at night, each gymnasium ground being lighted by a cluster of six arc lights on a specially constructed post 20 ft. high.

The walks in the 10 acre parks are all of concrete while in those of larger size they are generally of crushed stone with top dressing of coarse torpedo sand. The concrete walks are of the sections shown, 5 in. thick with top dressing 1 in. thick of mortar 1 of cemet to 1½ torpedo sand. On the street sidewalks where curbing is used the curb is laid 5 in. below grade and the walk over the top of it. This is partly for sake of better appearance and partly to prevent the pushing out of line of the curb by the expansion of the concrete walk —a condition so often seen at the ends of long lines of walks. The best results have been obtained by laying the walks with a ¾ in. expansion joint every 40 or 50 ft. The intermediate joints may be paper or sanded joints. Cut joints are not satisfactory as the cuts some times close up or are not deep enough to prevent the stones from cracking elsewhere than in the joints. It is not good construction to from the open joints in the body of the stone and trowel the finishing coat continuously over the joints depending on cutting through afterwards to meet the joints below. It cannot be done accurately every time and unsightly cracks are sure to appear. Some specifications call for ⅛ in. open joints to be made between every pair of stones by the insertion of a metal strip while laying. While this works well in curbs we do not find it is good for walks. Small gravel, harder than the concrete, lodge in the joints and when the walk expands under heat small pieces are chipped out of the finished top of the stone at the joints where the gravel are wedged in. An occasional larger expansion joint can be kept clear of gravel that would be harmful, while the ⅛ in. joint cannot.

Crushed stone walks and drives are made of the section shown with a crown of about 4 in. in a 10 or 12 ft. walk and 9 in. in a 35 ft. driveway. The section in the illustration is of a 50 ft. drive and 10 ft. walk with a 12 ft. planting space between. In the walks, which are generally 4 in. thick, stone not exceeding 1½ in. is used with enough of the smaller sizes and screenings to make a compact smooth surface. In the drives, which are from 8 to 12 in. thick, the coarstest stone is 3 in., filled with smaller sizes down to ⅞ in., and finally with the minimum quantity of coarse screenings needed as a binder and filler. Each grade of stone is heavily rolled as spread, the theory being the nearer we come to making a mosaic of the coarse stone and the less screenings needed to fill remaining voids the more durable the road surface. No "binding gravel" or mixture of clay and gravel is used in the South Park roads as a binder on account of its unstable character, and granite or other hard stone is practically discontinued as a surfacing material, because on our pleasure drives the problem is no longer to get a material hard enough to withstand the abrasion from iron shod hoofs and wheels, but to get a surface of

a texture and toughness sufficient to resist the traction and suction of automobile tires.

It may seem I am getting somewhat away from my subject when I describe the construction of a driveway that may belong to a boulevard or a parkway for the use of vehicles, but some of the new small parks have drives through them, others are now linked together by the boulevards, and *all* may be some day, with further extension of the boulevards.

The suppression of dust on macadam roads, walks and playground areas where grass cannot be maintained is a very serious problem in park maintenance. The time honored method of sprinkling with water is not entirely satisfactory. It is expensive and requires constant repetition. Surface treatment with coal tar preparations and asphaltic oils has been tried on a number of the drives and walks of the South Parks with much success. The cost has been from 5½ to 6½ cents per square yard for the first treatment which will last from one to two years according to amount of use. It not only goes far towards suppressing dust, reducing sprinkling by at least 60%, but it adds greatly to the life of the wearing surface of the road. What the condition will be after the second year, or what further treatment will be required cannot now be told, as its use does not extend over a longer period.

The method of application, is to spread it hot, about ¾ gallon per square yard, with a layer of limestone chips over it while still soft, and roll thoroughly. This is preferred to oil applied frequently in the form of an emulsion with water, because each application leaves the surface in a sloppy, oily condition. It is better to make one thorough application, cover it with stone screenings and have done with it.

All the small parks under the jurisdiction of the South Park Board are enclosed with substantial iron fencing. It is of simple design, 5 ft. 6 in. in height, 8 ft. panel lengths, with one inch square line posts set in concrete bases. At all corners, intersections and gateways, concrete posts 18 to 24 in. square are built, with moulded cap and ball on top. 46,000 lin. ft. of fence of this type was built in the small parks in 1905-6 under one contract, said by the manufacturer to be the largest contract for iron fence ever let.

Concrete has been used for a great variety of purposes in the Small Park construction, and it seems eminently adapted therefor. It has two essential qualities, permanency and pliability. It is as permanent in buildings as stone or brick, it can be formed or moulded to a greater variety of shapes or conditions and is cheaper than either unless it be compared to the very cheapest grade of brick. In moulded work there have been made steps, railing for walls and bridges, drinking fountains, columns, architectural ornaments, caps and balls for fence posts, seats, bases for lamp posts, walk catch basins, flower vases, etc. Most of these articles are faced with mortar of proportions 1 to 2½ or 1 to 3, but in a few

cases where the masses are small, as in seats and drinking fountains, the whole thing is made of mortar. The moulds are made either of wood or galvanized sheet iron. The surface is generally treated with an acid preparation to remove the skin of cement that forms on the surface and to expose the grains of sand or other aggregate. In this way much of the effect of cut stone is produced. Granite may be closely imitated by using crushed granite as the aggregate, or different kinds of sandstone by the use of the proper kind of sand with, perhaps, the addition of a little mineral coloring matter. Lamp-black, mineral red and yellow ochre have been used to color steps, bases and walks—anything of concrete on or near the ground—to relieve the glare of light on a smooth grey surface.

In nine of the small parks the buildings have been constructed entirely of concrete. They are monolithic structures with but little reinforcement in any part. They are generally one, or at the most two, story structures of simple design, with broad spreading roofs and plain wall surfaces. The concrete is a limestone concrete without color or treatment of any kind. The proportions are one of cement, three of limestone screenings and three of crushed limestone of the size known as quarter inch. It is mixed quite dry and crumbly, just so no water will flush to the surface when rammed. The result is a soft grey, grainy, somewhat honeycombed surface of uniform texture that does not show form marks and does not stain readily. No efflorescence has ever appeared on this concrete, and, of course, there are no half cracks on the surface.

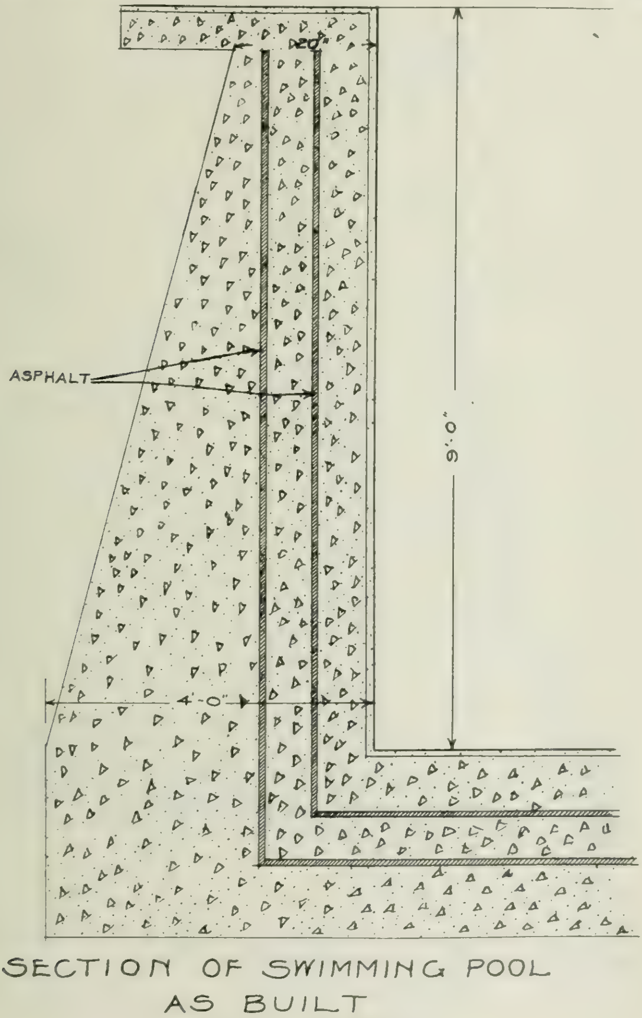
Generally the park buildings have no plaster or other finish on the interior walls, only the plain concrete with sometimes a coat of paint, either oil or distemper, to give a little color. The porosity of this concrete is the greatest objection to it. Exposed directly to the action of water, as it is in the shower bath rooms and gymnasiums, it readily absorbs moisture enough to show damp on the outside. To overcome this, the inside of the walls in the bath and toilet rooms have been plastered with cement mortar with a percentage of waterproofing compound. This has been effective. Although the walls are so permeable and must absorb a good deal of water from rains, frost has no perceptible effect on it. Even the sharp corners of walls and projections are absolutely unaffected by the action of moisture and frost.

Besides the extensive use of this kind of concrete in buildings it has been used in retaining walls and reinforced arch bridges as a facing only, in thin walls for service yards, columns and fence posts with equally satisfactory results. About 3,000 lin. ft. of service yard walls, from 8 to 12 in. thick and from 9 to 12 ft. high have been built in the ten small parks that are completed. These walls are exposed on both sides and have no protection except a tile coping on top, and no precautions have been taken except to provide expansion joints every 30 or 40 feet.

Our experience in the construction of various kinds of walls

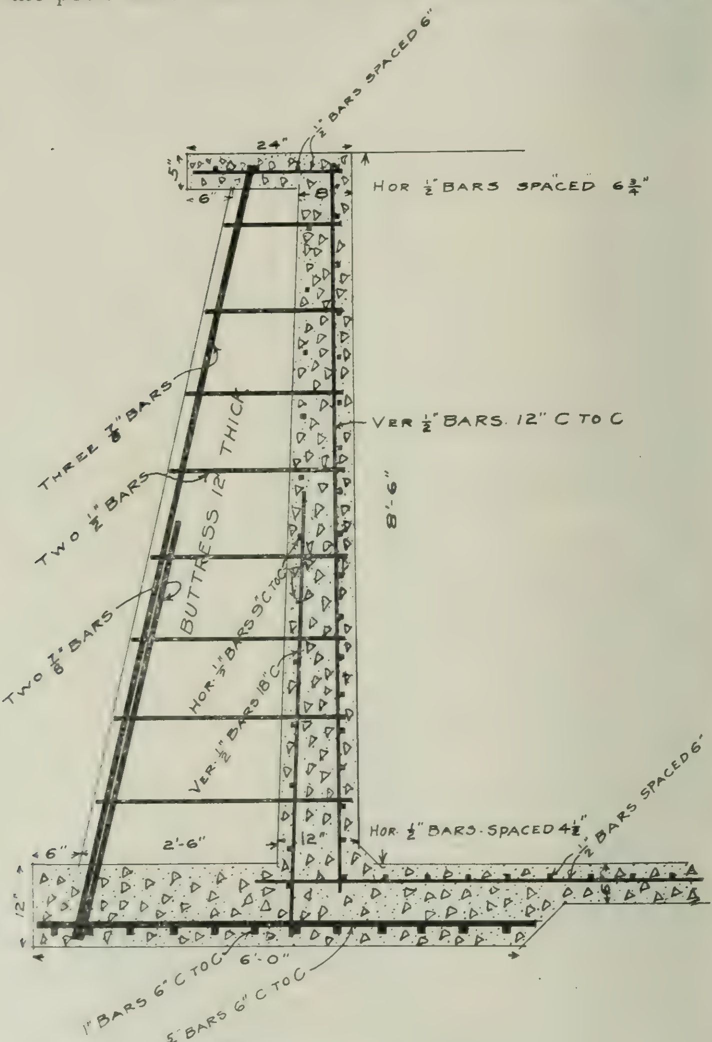
emphasizes the necessity of providing plenty of joinst for expansion or contraction where these forces are not cared for by steel reinforcement. The thinner the wall and the more exposed, the greater the need for joints.

In the construction of the open air swimming pools quite a problem was found. The construction that has been used is unreinforced walls and bottom without joints. The walls were 9 ft. high above floor line in the deep ends of the pools, 4 ft. thick at the base and 20 in. thick at the top. The bottoms were 2 ft. thick. Two layers of



Concrete Construction.

asphalt mastic were provided 6 in. and 12 in. respectively from the face of the concrete next the water. The walls and bottom were built in three layers, with the asphalt applied as plaster when the forms were removed from each layer. The result has been cracks and plenty of them, more than were anticipated. In a few cases, where the pools were founded on a cinder fill or on sand that was



SECTION OF SWIMMING POOL
PROPOSED

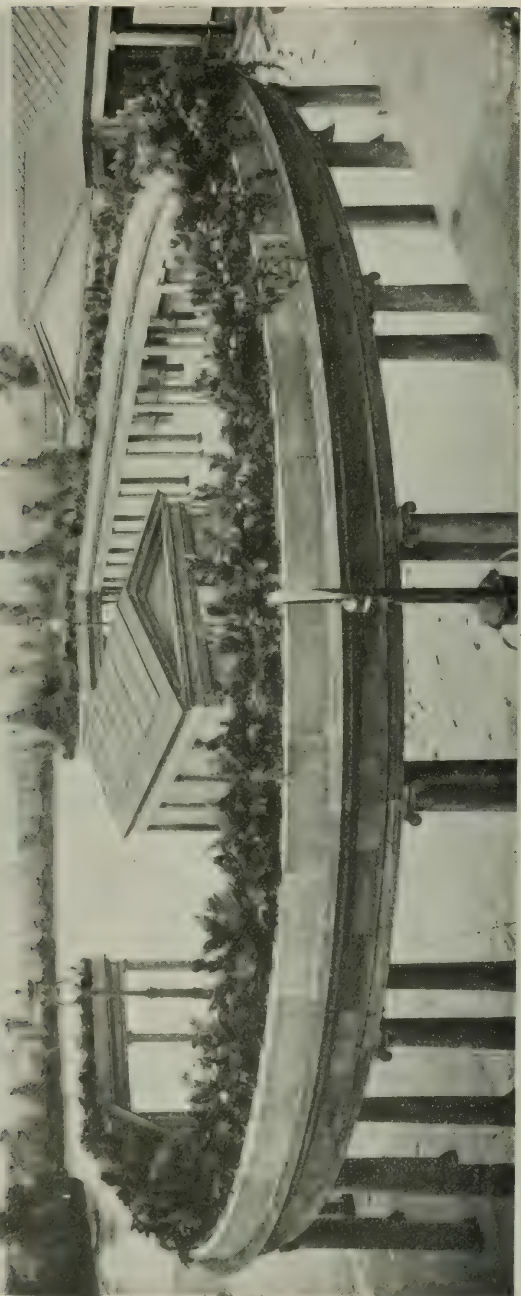
Concrete Construction.

well drained, the cracking was not so very bad, but generally the upper layer of the bottom broke up badly, requiring considerable repairs, and the sidewalls cracked in a lesser degree. The water evidently found its way through the first layer of concrete and we may assume formed a thin sheet on the mastic, where it did not find a crack to go on through, and when the tank was emptied there was a hydrostatic head on the top layer. It was not considered prudent to leave the pools full of water during the winter, so when the frost came, it found some water below the top layer of concrete on the mastic which in freezing helped break up the concrete. And so the work of destruction went on. The remedy proposed is to build the next pool of reinforced concrete, designed especially to resist contraction due to extreme changes of temperature. The walls and bottom would be built in one layer without joint. The walls would be 12 in. thick at base and 8 in. at top. A buttress would be built on the back every ten feet and the walls reinforced horizontally to act as slabs supported by the buttresses. This design is proposed instead of a wall designed as a cantilever supported at the bottom and reinforced principally vertically, because the heavy horizontal reinforcement is in the proper direction to resist temperature and contraction stresses. When the pool is full it is expected the pressure on the side walls will be practically balanced, but when empty the pressure from the outside will be that of a partially saturated fill. Also when the pool is full it is figured the foundation will be compact enough to carry the load without enough compression to produce serious bending moment in the bottom. The foundation will be made for a depth of 18 in. of cinders and well underdrained by lines of clay tile to prevent any upward pressure. The only waterproofing will be in the finishing surface coat and may be some waterproofing compound used in the mortar, or a treatment of the surface after completion. It would not be a mastic or a membrane as either would be evidently objectionable in such a position.

As to the results accomplished, or the "Sociological" side of the matter, a few statistics may be interesting and instructive. Daily records are kept of the number of people who make use of the various Small Park facilities. For the year 1906 the total number is as follows:

Indoor Gymnasiums	371,158
Shower Baths	806,032
Outdoor Gymnasiums and Playgrounds	2,278,847
Swimming Pools	765,299
Assembly Halls	186,534
Club Rooms	28,239
Reading Rooms	608,274
Lunch Rooms	429,312
	5,473,695

These figures mean those who actually participated in the various



Concrete Construction in McKinley Park.

exercises, games or recreations afforded. The visitor or the one who simply walks around, sits down or looks on is not counted, though he, of course, is making use of the park and doubtless deriving benefit therefrom.

The proportionate use of the facilities offered vary in different parks, that is, the park that holds the record of the largest number of bathers does not hold the record of largest attendance in the gymnasiums, etc. One swimming pool, Ogden Park, had 107,076 swimmers in 1906 but this number was exceeded by McKinley Park

View in McKinley Park.

in 1904 before other pools were finished and opened to the public.

Statistics might be multiplied, but they belong more properly in an official report than in a paper like this. Suffice is to say that many of the facilities provided are overcrowded and there is a demand for enlargement all along the line and a great cry from other sections of the South Side to build more Small Parks.

The need of such institutions as the small parks in a city like Chicago scarcely needs further proof, and if proof was needed it is scarcely within the scope of such a paper as this to offer it. One needs but a slight acquaintance with the city to understand there are thousands of men, women and children who are out of reach of the older and larger parks and whose only breathing spaces and playgrounds are the streets. These people need something more than merely the freedom of a park, and in the free gymnasiums, bathing facilities, reading rooms, assembly halls and club rooms, and regulated playgrounds, the effort is made to furnish them something more.

In each park there is a manager in charge of the buildings with all necessary assistants to keep them in the best possible condition, and attend to the wants of the people; there are two instructors in charge of the gymnasiums, a man and a woman, working under a competent director of the Department of Athletics, and the necessary police to maintain order. No charge is made for the use of the buildings or any of the facilities provided.

In the construction of the small parks there are two fundamental ideas—simplicity and permanence—and in their management also

Typical View of the Reading Rooms.

two—order and cleanliness. Each of these is expected to teach its own lesson and bear fruit. That they have borne fruit is evidenced by the increased respect for law and order and cleanliness that is apparent in the neighborhoods where they have been established.

The people of Chicago have acted with characteristic largeness and liberality in these matters and the result is that there has been and is being established the largest and most perfectly appointed system of public recreation grounds in the world.

Discussion.

President Abbott: It is apparent, after looking at these pictures (especially the last one thrown upon the screen), that the inevestment which the City is making for this Small Park System is a profitable one. The children who take advantage of what these parks offer have, as a rule, no other convenient recreation grounds, and if the small parks were not scattered as they are, the children would be obliged to seek playgrounds in the larger parks miles away, and naturally would not frequent them as often as they do the smaller

ones. I presume the entertainment in healthful sport does not cost the Park Commissioners more than a few cents for each child, and where else could they get such profitable entertainment at a price many times greater than that?

We notice in an engineering way that the greater part of the work is in concrete, and I presume without modern concrete construction a great deal of this work would not be possible. Certainly if the same amount of money were to be spent in buildings of other construction, the expense would be much greater and the structures would not be so enduring, and naturally we would have less of them.

Mr. A. C. Schrader, M.W.S.E.: The West Chicago Park Commissioners entered into this work only this year, and they are not very far advanced in the construction of small parks. Plans are made for three, but only two of the parks are in process of construction. The plans are practically along the same lines as those of the South Parks system, except that the buildings will be constructed of brick throughout rather than of concrete.

These three small parks are located in the most densely populated sections of the west side of the city, where there is but little or no place for play or recreation for children. One small park is bounded by Chicago Ave., Cornell St., Noble St., and Chase St., and contains 8.12 acres. Another is bounded by 20th St., 21st St., Fisk St. and May St., and contains 3.85 acres. A third small park proposed is bounded by Barber St., 14th Place, Union St. and Jefferson St., and contains 2.89 acres.

There can be no doubt of the beneficial effect upon a community, resulting from the existence of small parks and playgrounds, provided they are well managed

The swimming pool, playgrounds, outdoor and indoor gymnasium, shower baths, reading and lecture rooms, are features usually introduced and should be conducive to physical as well as mental development, especially where the management provides correct direction of effort.

The work of the South Park Commissioners is particularly commendable and shows discrimination in the introduction of certain features into the small parks and shows careful management. With the continued growth of the city it is apparent that the west side is particularly in need of a greater number of small parks and playgrounds. Aside from this we should not lose sight of the possibility of acquiring an outer belt system of parks and drives.

Mr. J. P. Ball, M.W.S.E.: I think the officials of the South Park Commission are to be highly commended for the successful way in which they are carrying out these improvements.

Mr. T. L. Condron, M.W.S.E.: I have given a good deal of attention to tank construction, as we might call it, and was much interested in the cross-section of the reinforced concrete tank which Mr. White showed us. We have just completed designs for a swimming pool, to be built by the Lincoln Park Board, and have adopted a very

different cross-section from the one shown. I think the one shown is doubtless an excellent design, but believe the one we have adopted is equally as good. We have recognized for some time the fact that you cannot make monolithic concrete waterproof by the use of mastic or any waterproofing material you may use, as Mr. White has clearly explained, and the most essential thing is to so construct the walls of the reservoir that they will not crack open from temperature, contraction or shrinkage of the setting of the concrete or frost action.

In the tank we have designed we have assumed that the pressure on the bottom, which is the most critical, will be that due to frost and of a sufficient amount to lift the side walls of the tank, together with the resistance the earth may offer in friction. If you have the bottom strong enough to resist this action it will not be broken by the frost.

I think the work of the South Side Board is of such character that we cannot begin to appreciate what it means to this community, in the enormous influence it will have in elevating the future citizens of our city. There is nothing I know of in the work of the churches, social settlements, or any of the other great efforts in this community to raise the standard of our citizens, that surpasses what we may believe will be the effects of these small parks. The sociological feature impresses us the most, and when we see, in addition to this, with what great care and evident ability the engineering work has been done, we can certainly be proud of the fact that we have a South Park Board, and that we have engineers connected with the South Parks who are working for our interests in this city. I know that the attention of the whole country is being called to the small parks work being done in this city.

Mr. J. H. Warder, M.W.S.E.: I will call attention to the map showing the location of the small parks. I understand that, with the completed system of parks as planned, the residents throughout the South Side will have a park or playground within a distance of a mile and a half. Certainly this scheme which the South Parks Commission is developing is a very comprehensive one.

Mr. Condron: I understand that the parks are used, to a very large extent, by adults in the evening?

Mr. White: Yes, that is true; the hours are arranged, I think, in all cases for the interior work so that the evening is devoted to the adults and the day to the children. Of course the pictures were taken in the day-time, and a large proportion of them show children at play, but that does not mean at all that they are the only ones using them. The records we have kept distinguish in many instances between the children and adults, but not in all cases, so we cannot show exact results. The bathing facilities are used by the adults, especially in the districts about the manufacturing centers, and the gymnasiums are crowded by working men and boys, in the evening.

Mr. M. K. Trumbull, M.W.S.E.: We are indebted to Mr. White for the interesting paper that he has presented to us. I am glad that our President and Mr. Condron have referred to the sociological feature which should be brought out very forcibly in connection with the Small Parks System.

Whenever I hear a discussion on the subject of small parks it seems fitting that the name of Jacob Riis should be mentioned—a man who has done so much toward advancing this great branch of sociological work.

It is very fortunate that we have such institutions as the South Parks Board, the West Parks Board, and the Lincoln Park Board, and in carrying out the "City Beautiful" idea it is a splendid thing that they do not confine themselves to the sociological feature alone. They are attempting to build up the city along the lines which have been spoken of so much during the last few years, and, as we all know, the city officials of Chicago are endeavoring to suppress the smoke nuisance, the railroad companies have elevated their tracks in the busiest portion of the city to a great extent, and when the time comes when the smoke can be prevented from passing out in black clouds from the chimneys of office buildings, mills, factories, and from railroad locomotives, we will have gone far toward the realization of the "City Beautiful."

It is to be regretted, however, that we have not some Commission analogous to the South Parks Board to take care of the central portion of the city. The Board of Supervising Engineers is doing everything possible toward the improvement of elevated and surface lines of transportation, but it seems to me, as we look forward to the future twenty-five to fifty years, we will find that the business area is greatly restricted by the physical limitations—the Chicago river on the north and west, Lake Michigan on the east, and the railroad terminals on the south. It would be a splendid thing if a Commission might be appointed which would look toward the expansion of the business center at the same time this question of transportation is before the public, for this is a problem which will demand solution at a time not far distant in the future.

Mr. C. K. Mohler, M.W.S.E.: I would like to ask Mr. White if he can tell us where the idea of small parks originated—or if it originated with Mr. Riis? The results of such work as his in New York City have been very marked. In some places they have bought up whole squares of tenement houses, torn them down and established amusement parks. I would also ask Mr. White if he can tell us anything in connection with the history of that movement. The need of these playground parks in certain districts can hardly be over-estimated. Of course in the outlying districts before they are closely built up the children can use the vacant lots for playgrounds, but as soon as these lots are built up that feature will be gone, and unless amusement parks are provided they will be obliged to use the streets as their only playground. There is no question but that all children

should have an available playground, which is a greater factor than is commonly recognized in keeping them out of "mischief," and in producing "desirable citizens."

Closure.

Mr. White: As to the historical side of this question, I hardly think I am competent to give a very clear statement, but the small park idea, certainly did not spring forth, fully developed, at first; it has been a matter of growth. Undoubtedly the places where ideas of this sort were first taken hold of to any extent and developed in this country were such communities as New York in its Tenement House reforms, and Boston. Boston, I think, had the first small playground—the first municipal organization of that sort—and the work has been taken up by men and women of recognized standing all over the country from a sociological standpoint. In my paper I did not speak of any one personally, as I felt that I did not have the data to present it in the right light. The credit is undoubtedly divided among quite a number of our best people, and I think the development of the idea as exemplified in the Chicago Small Parks was in this country. While, of course, the same sort of thing is going on in European cities, I know of no place where the idea has been developed as completely and to as large an extent as here in our own city.

The vacant lot as a playground is, of course, a very nice thing, but as the city grows up around it, the vacant lot becomes scarcely better than the street, and the need in a city where there is a large population growing into men and women is to have the right example set before them, and have them trained in the right direction in their play as well as in work. The great objects to be attained in the playground idea are—order and respect for proper control. These are features very strongly put before the people in the construction and management of these enterprises. I think the mere fact of the existence of a well ordered small square or park, in a poor and crowded district, has an enormous civilizing and improving influence.

IN MEMORIAM

WM. D. HOTCHKISS.

Colonel William Dye Hotchkiss, Assistant City Engineer, a member of the Western Society of Engineers for twenty-one years, died at his home in Chicago on the 3rd of June, 1907, at the age of fifty years. He was born in Chicago April 18th, 1857, where he attended the public schools, and later the Massachusetts Institute of Technology at Boston, from which he was graduated as a Civil Engineer. He married Miss Carrie E. Carr in 1884, who survives

WILLIAM DYE HOTCHKISS

him with a daughter, and a son who is also a member of our Society.

Colonel Hotchkiss' first engineering work was on the location survey of the Santa Fe Railroad westward from Albuquerque, N. M., in a region where each member of the party carried firearms during the day, and at night stood guard by reliefs over their camps for protection from hostile indians, who had killed a preceding survey party. After a term of service as a division engineer in the construction of the Chicago and Northwestern railroad from Milwaukee

to Madison, Wisconsin, he entered the Engineering Department of the City of Chicago. There he was continuously employed to the time of his death,—a period of over twenty-four years—being at home in all the varied engineering work of the City. In compliment to his patriotism, loyalty of service and fidelity to his duties, the City of Chicago paid him his full salary during his year's service in the army, in the war with Spain.

He was the only son of General C. T. Hotchkiss,—a long time and well known resident of Chicago, a veteran of the Civil War, and for several years following the great Chicago fire a prominent public official. The son, true to his inheritance of patriotic American life, early entered our local military service as an officer in the second regiment Illinois National Guard, of which he was Lieutenant Colonel and its Treasurer for ten years. In recognition of his well known courage and ability, he was given command of important operations when the regiment was called out at different times during local disturbances.

With that regiment he volunteered for the Spanish-American War, and in the absence of its Colonel, Lieut.-Col. Hotchkiss commanded the regiment in its transport from the United States to Cuba, and during the military proceedings at the lowering of the Spanish and hoisting of the American flag over the Island's Capitol Building and Moro Castle in Havana.

A capable, modest, and honest man, always loyal to his convictions of right in matters with which he had to do, a genial and companionable gentleman in his home and with his associates in every day life, is the fitting history in epitome of Colonel Hotchiss' upright life.

(Signed) Ricard O'S. Burke,
T. Frank Quilty,
B. E. Grant,
Committee.

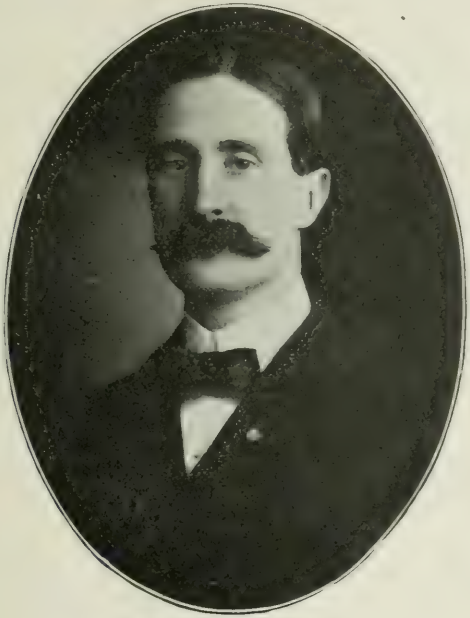
William Samuel Love.

By the death of William S. Love, which occurred December 11th, 1907, at his home in East Orange, New Jersey; this Society and the Engineering Profession in general, suffered a great loss.

Mr. Love was born May 20th, 1865, in St. Louis. His early education was in the St. Louis grammar schools, and he went from them to Smith Academy, the classical preparatory school of Washington University, St. Louis. Having strong mechanical tastes he did not graduate from Smith but changed over to the manual training school, which had just been opened. He spent one year there and graduated with the first class, in 1883, after which he entered the freshman class of the Engineering Department of Washington University. His original intention was to follow civil engineering as a profession and he therefore accepted a position with a surveying

party on the Texas & Pacific R. R. in Arkansas, at the end of his junior year. After a year spent in railroad work he decided to complete his course in the department of mechanical engineering, and returning to Washington University, graduated with the degree of Bachelor of Science in Mechanical Engineering, in June, 1888.

Immediately after graduation, he accepted a position with the Street Department of the City of St. Louis, remaining with them until the early part of 1889, when he entered the service of the Pond Engineering Co. From the Engineering office he was transferred to the Sales Department, where his efforts were so successful that when the Company was reorganized as the Pond Machinery Co., Mr.



WILLIAM SAMUEL LOVE

Love became a partner and was made Secretary. The Pond Co. had then a number of branch offices and it was decided to give Mr. Love charge of the Chicago house, to which city he moved in the summer of 1892. The Pond Machinery Co. decided to close up its business shortly after, and Mr. Love personally succeeded to its agencies in Chicago, particularly those of the Armington & Sims Engine Co. and the Hoppes Mfg. Co. In 1895 he took charge of the Chicago Office of the Abendroth & Root Mfg. Co. and conducted this business successfully until 1897, when the Wheeler Condenser & Engineering Co., of New York, opened an office in Chicago, and Mr. Love accepted the position of Western Sales Manager. So successful was his work in Chicago that it led to his appointment as General Sales Manager of the Wheeler Company and his removal

to New York in December, 1906. While in charge of the Chicago office he took contracts for many important condenser and cooling tower installations, among them being the Union Light & Power Co., in St. Louis; the "Alley L" in Chicago; the Metropolitan Street Ry., in Kansas City; the Central Illinois Construction Co. Power Houses at Riverton, Ill., and Peoria, a plant of 75,000 lbs. steam per hour from steam turbines, using the exhaust from non-condensing engines, in the Power House of the East St. Louis & Suburban Ry., and a 100,000 lb. Barometric Condenser & Towers, at the American Car & Foundry Co., St. Louis.

Mr. Love was the son of the late James E. Love, of St. Louis, and was married in Chicago, July 2nd, 1892, to Miss Annie Archibald, of St. Louis, who survives him, as do also a seven year old son, his mother and three sisters. He was a member of the Western Society of Engineers, the American Society of Mechanical Engineers, the Engineers Club of Chicago, the Union League Club of Chicago, the Engineers Club of New York, the Loyal Legion both in Chicago and New York, and of the Fourth Presbyterian Church of Chicago. In all these his interest, energy and ability made themselves felt. Being of a whole souled disposition and exceedingly kind hearted, it is not strange that he had many warm personal friends. His many engaging personal qualities, his loyalty and the energy and enthusiasm with which he undertook whatever came in his way endeared him to all with whom he came in contact. To these his memory will ever be an inspiration.

(Signed) J. W. Schaub,
D. W. Roper,
Grant Beebe,
Committee.

PROCEEDINGS OF THE SOCIETY.

MINUTES OF THE MEETINGS

ANNUAL MEETING, JANUARY 7, 1908.

The 38th annual meeting (No. 621 of the Society) was held Tuesday evening, January 7, 1908. The meeting was called to order by President Abbott about 7:15 p. m. in the library of the Chicago Athletic Association building, 125 Michigan Avenue, with over one-hundred members and guests present.

The Secretary reported from the Board of Direction the result of the election of officers for the year 1908, as reported by the Judges of Election, viz.

President	C. F. Loweth
First Vice President	J. W. Alvord
Second Vice President	P. Junkersfeld
Third Vice President	D. W. Mead
Treasurer	A. Reichmann
Trustee for three years	L. E. Ritter

Also that Messrs. John Brunner and W. C. Armstrong remain as Trustees for one and two years respectively, and that the three Past Presidents—Messrs. E. C. Carter, B. J. Arnold and W. L. Abbott—with the preceding, constitute the Board of Direction for 1908.

The Secretary also read the reports of two committees on the award of the Chanute medals for papers presented before the Society in 1905 and 1906, as follows:

CHICAGO, December 14, 1907.

To the Board of Direction, Western Society of Engineers, Chicago.

GENTLEMEN: We, the undersigned, have carefully considered the papers submitted to us as a committee on award of the Chanute Medals for the year 1905, and recommend that the awards be as follows:

Electrical Engineering—To Charles H. Smoot, for his paper on "An Experimental Determination of Air-gap Reluctance."

Mechanical Engineering—To C. E. Sargent, for his paper on "The Prime Mover of the Future."

Civil Engineering—To T. L. Condron, for his paper on "Strength of Reinforced Concrete."

Very respectfully submitted,

ISHAM RANDOLPH
(Signed) WM. S. MONROE,
MORGAN BROOKS,
Committee.

CHICAGO, December 7, 1907.

To the Board of Direction, Western Society of Engineers, Chicago.

GENTLEMEN: Your committee appointed to recommend the award of the Chanute Medals for the most meritorious papers on Civil, Mechanical and Electrical engineering subjects, presented before the Society by members thereof during the year 1906, beg to report that they have carefully considered the papers, and recommend that the medals be awarded as follows:

Civil Engineering—To Mr. George H. Bremner, for his paper on "Areas of Waterways for Railroad Culverts and Bridges."

Mechanical Engineering—To Mr. W. L. Abbott, for his paper on "Some Characteristics of Coal as affecting Performance with Steam Boilers."

Electrical Engineering—To Mr. Rudolph F. Schuchardt, for his paper on "The Rotary Converter Sub-station."

The committee have also considered the desirability of giving, with the medals, an engraved diploma of award, and recommend that this be done.

Respectfully submitted,

GEORGE A. DAMON,
(Signed) B. E. GRANT,
C. E. SARGENT,
Committee.

Soon after 7 p. m. the members and guests adjourned to the new Banquet Hall of the Chicago Athletic Association, where dinner was served. At the conclusion of the dinner, Retiring President Abbott called the meeting to order and addressed them on the history and growth of the Society, particularly as related to the past year, 1907. As President-elect Loweth was absent, due to illness, Past President Abbott conducted the exercises of the evening, and introduced Mr. E. W. McKenna, of the Chicago, Milwaukee & St. Paul Ry Co., who addressed the meeting on *"The Railroads and the Interstate Commerce Commission."*

The Chairman read a telegram from Mr. Samuel Insul, President of the Commonwealth Edison Co., explaining his absence, as it had been expected that he would address the meeting. Dr. Edmund J. James, President of the University of Illinois, was then introduced, who made a very interesting address on the University. He made a plea for a more thorough grounding in mathematics and other underlying principles of engineering, even at the expense of some of the time now spent in manual training and the study of the more practical questions of the profession. The speaker closed his remarks by asking that those present give him by letter their opinion upon the propositions which he had presented.

Other addresses were made by Past Presidents W. H. Finley and Ralph Modjeski; also Messrs. C. V. Weston, A. N. Johnson, D. W. Mead, and Col. W. H. Bixby.

The meeting adjourned soon after 11 p. m.

Electrical Section January 10, 1908.

The regular (and annual) meeting of the Electrical Section (No. 622 of the Society and No. 29 of the Section), was held Friday evening, January 10, 1908. The meeting was called to order about 8:15 p. m., with Vice Chairman, D. W. Roper presiding, and about 45 members and guests present.

The minutes of the meeting held December 13, 1907, were read and approved.

The Chairman explained that this was the meeting for the election of Chairman, Vice Chairman and one member to serve three years, to serve on the Executive Committee; also that a nominating committee had selected a ticket which had been posted in the Society rooms, and it was in order to be voted on.

Mr. Cravath was invited to assume the Chair, and the Secretary presented the ticket, which was as follows:

For Chairman, to serve one year, Mr. D. W. Roper.

For Vice Chairman, to serve one year, Mr. H. R. King.

For Member of Executive Committee, to serve three years, Mr. E. N. Lake.

No other nominations were offered, and on motion of Mr. E. F. Smith the work of the committee and the nominations presented were approved, whereupon the persons mentioned were declared elected.

Mr. Roper, as Chairman-elect, then took the Chair and announced the paper for the evening to be—*Electric Elevators for High Buildings*—by Mr. John D. Ihlder, of New York. As the author of the paper, on account of illness, was not able to be present, his paper was read by Mr. H. Russell Smith, of the Otis Elevator Co., Chicago Office, and was illustrated by a number of lantern slides.

In the discussion which followed the presentation of the paper, Mr. J. W. Mabbs, of Chicago, described, with many lantern slide illustrations, the special features of the Mabbs electric elevator which had been installed in the Board of Trade building, Chicago. The paper was also discussed by Messrs. D. W. Roper, E. F. Smith, S. M. Bushnell, Geo. M. Mayer, A. Scheible, John Blake, R. F. Schuchardt, P. Junkersfeld, F. G. Cox, T. W. Heermann, and H. Russell Smith.

On motion of Mr. Junkersfeld, a vote of thanks was tendered to Mr. Ihlder for his paper, and also to Mr. Smith for his presentation of it.

The meeting adjourned at about 10:15 p. m.

Extra Meeting, January 22, 1908.

An extra meeting of the Society, No. 623, was held Wednesday, January 22nd. The meeting was called to order at 8:15 p. m. by President Loweth, and with about 50 members and guests present. The object of the meeting was further discussion of the paper by Past President H. E. Horton, on *"The Wrought Compressive Member for Bridge Trusses,"* presented October 2, 1907. Mr. W. C. Armstrong presented some written discussion of the subject, and the Secretary read a contribution to the discussion sent in by Mr. F. H. Bainbridge. Other remarks followed from Messrs. Andrews Allen, A. Reichmann, H. E. Horton and President Loweth. A letter was read from Mr. Bainbridge, suggesting that the Society, through a suitable committee, collect, collate and edit all possible reports of tests of full size compression members, as made and reported by the American, English, German and French engineers, such report to be published in our Journal, with the paper by Mr. Horton, and the discussion of the same. Mr. Horton offered a resolution to the effect that such a committee be appointed, and the resolution was duly carried.

The meeting adjourned about 10 p. m.

Regular Meeting, February 5, 1908.

A regular meeting (No. 624) was held in the Society Rooms Wednesday, February 5, 1908.

The meeting was called to order about 8:20 p. m. with Vice President Junkersfeld in the Chair and about 50 members and guests present.

The Minutes of the Annual Meeting held January 7th, and an extra meeting held January 22nd, were read and approved. The Secretary also read an invitation extended to the members of the Society to attend the Third Annual Meeting of the American Society of Inspectors of Plumbing and Sanitary Engineers to be held at the Great Northern Hotel, Chicago, February 10th, 11th and 12th, 1908. The letter of invitation was signed by John K. Allen, Chas. B. Ball and E. H. Donahoe, Committee on Program and Entertainment.

There being no further business, the Chairman introduced Prof. H. B. MacFarland, who presented his paper *"Test of a Small Suction Gas Producer Plant."* This paper has been printed and sent out in advance, so it was not read in full but abstracted and explained by the author.

Discussion followed from Messrs. P. R. Brooks, J. H. Warder, A. R. Swoboda, C. J. Atkinson, C. C. Robbins, G. M. Mayer, W. J. Miskella, A. W. Moseley, G. Gansslen and the author.

The meeting adjourned about 9:50 p. m.

Electrical Section February 14, 1908.

A regular meeting (No. 30) of the Electrical Section (being No. 625 of the Society) was held Friday evening, February 14, 1908.

The meeting was called to order about 8:25 p. m. with D. W. Roper, Chairman of the Section, presiding, and about 40 members and guests present.

The Minutes of the preceding meeting held January 10, 1908, were read and approved.

There being no other business to bring before the Section, Mr. James N. Hatch, M.W.S.E., was introduced, who read his paper on *"The Evolution of Electric Railway,"* which was illustrated by a number of lantern slide views. Discussion followed from the Chairman and Messrs. L. Nissley, W. E. Symons, Geo. M. Mayer and the author.

The meeting adjourned at 10:15 p. m.

Extra Meeting, February 19, 1908.

An extra meeting of the Society (No. 626) was held Wednesday evening, February 19, 1908.

The meeting was called to order about 8:15 p. m. with Mr. P. Junkersfeld, 2nd Vice President, in the Chair, and about 40 members and guests present.

There was no business to bring before the Society, so the speaker for the evening—Mr. Wilson E. Symons, M.W.S.E.,—was introduced who read his paper, *"The Passing of the Steam Locomotive."* The paper was illustrated

with many lantern slide views of various types of locomotives illustrative of its development from the earliest form to the present time. The relation between the development of the railways of the country and the increase in population was shown. Also the use of electric locomotives at congested terminals was brought out.

Discussion followed from Messrs. Abbott, Hatch and Junkersfeld, with a closure by the author.

The meeting adjourned about 10 p. m.

J. H. Warder, *Secretary.*

Address of Retiring President, W. L. Abbott, January 7, 1908.

Upon reading the address of Retiring President, Octave Chanute, I learn that the origin of our society was in a meeting of twelve eminent civil engineers called for the purpose in May, 1869. At first the name of the organization was the Civil Engineers' Club of the Northwest, but in 1880 it was changed to the one it now bears.

The membership at that time, after twelve years of existence, was only 139, but in 1890 it had grown to 265, and the society congratulated itself upon the vigorous growth it had enjoyed. During the next ten years the membership increased to 502; and now, after a lapse of eight years more, we count a membership of an even 1,000.

Having reviewed the past, it may not be out of place here to speculate upon what our growth will be in the future. Past President Arnold is a prophet of reputation and honor even in his own country, but not having him on my staff, I venture to do some prophesying myself.

During the last three decades our annual growth has averaged 7%, during the past two decades it has averaged 8%, and during the first seven years of the present decade it has averaged 9%. In view of this steady growth at an increasing rate, it would not be unconservative to say that, as our membership has doubled during the past eight years, it will double again within that length of time in the future.

As far back as 1901 complaint was made of the inadequacy of our library and meeting rooms, and that which then was a complaint has now become a pressing demand for relief. But what will the condition be eight years from now if relief is not obtained in the meantime?

Our financal condition also has shown a moderate but gratifying improvement. Five years ago our invested interest bearing surplus amounted to \$5,000.00; to-day it is \$12,000.00, \$2,000.00 of which represents the profit of last year's business, aside from the donation of \$1,000.00 made by Retiring President Arnold.

But no engineering society can justify its existence by a mere accession of members and money. The Western Society exists because the engineers of the west feel the need of such a medium for the exchange of ideas as the Western Society and its journal should afford, and the fact that western engineers are adding their names to our roll is evidence that in a measure the Western Society is fulfilling its mission.

I say "in a measure" because the benefits to be derived from such a society are limited only by the energy and wisdom of its leaders and by the zeal and enthusiasm of its members.

It is true that the quantity of our papers has increased greatly in the past few years and that the publication committee is able to tell for months ahead where their papers are to come from, instead of living from hand to mouth as was formerly the case.

But while the quantity has increased, I doubt that there has been a corresponding improvement in quality, although our journal is one of which we have no need to be ashamed. It is evident, however, that occasionally papers are offered and accepted which are carelessly prepared or are upon relatively unimportant subjects.

In the olden days, when they knew that the success and the life of the society depended upon their own efforts, the greatest civil engineers of the west contributed papers and regularly attended the meetings. Now, however,

the older men, probably thinking that the society is in safe hands and that they have done their duty, are seldom heard or seen at our meetings.

Past President Chanute, in his address previously referred to, spoke of the desirability of getting more electrical and mechanical engineers into the society. I estimate that at the present time about one-third of our members are in these two branches of engineering and that they are contributing nearly two-thirds of the papers, while the civil engineers are contributing but one-third.

It is certainly up to Mr. Loweth to put the gad to the shirking horse and make him do his share of the work.

Referring again to the demand for better and larger library and meeting room:

Several years ago it was customary to have a committee on permanent quarters, whose duty it was to look for a commodious and permanent home for the society. I say "look for" rather than find, because in those days the society had neither a surplus nor a surplus revenue, and so these successive committees went forth like the knights of old in search of the holy grail, without the slightest idea where such a place could be bought without funds and supported without revenue and eventually these committees were discontinued and the search abandoned. To-night, however I am happy to say that we have found the grail. It was lying just outside of our door.

Your Board of Direction has unanimously accepted a proposition made by the agents of the Monadnock Building, whereby the society will acquire a ten-year lease to all of that portion of the seventeenth floor which lies to the north of that bank of elevators in front of the secretary's office and extending as far as the fire wall which divides the old building from the new. This includes the space now occupied by the corridor and the rooms on both sides of it,—in all, something over sixty feet square and nearly double the area of our present quarters.

In this space it is planned to provide ample room for our growing library, commodious, light and cheerful reading rooms, and an inside meeting room free from exterior noise, with a 14-foot ceiling, which will comfortably seat 75% more than can be accommodated in our present meeting room.

The credit for obtaining the new quarters must be spread over three administrations. During Mr. Arnold's administration the dues and fees were raised, so that now our income is considerably above our expenses, and in addition thereto Mr. Arnold, upon retiring from office, gave to the society his check for $1,000.00, thereby establishing a beautiful custom, to which it is expected all retiring presidents shall conform, except on leap years.

This donation to our treasury and the increased revenue from dues and entrance fees put the Board of Direction, in a position to take advantage of a fortuitous lapsing of the leases to the space desired at the time it was wanted, and now upon Mr. Loweth and his associates devolves the duty of deciding upon definite plans and carrying out the work.

Mr. Arnold's administration furnished the money, during my time the space was secured, and Mr. Loweth will do the work and pay the bills, which it is estimated will be in the neighborhood of $6,000.00.

Our operating expenses, which have been in the neighborhood of $1,200.00 a month, will now be something over $1,300.00 a month, and this to provide facilities nearly double those we now have.

During the coming summer vacation the alterations to our rooms will be made, and when the meetings begin again in September it will be in our larger quarters.

This step, we all must admit, will be the beginning of a new epoch in our history, and with it will come new responsibilities and new problems for the President. Alone he can accomplish little, but with the loyal support of all during this critical period, the Western Society of Engineers will be placed on a higher plane and in a sphere of greater influence than ever occupied before.

To the officials of the society who have colabored with me, and to the members who have at all times rendered such loyal support I return my sincere thanks, and I bespeak the same generous support for my successor.

ANNUAL REPORTS

Report of the Judges of the Election.

January 8, 1908.

To the Western Society of Engineers, Chicago.

Gentlemen: The undersigned Judges of Election, having canvassed the ballots cast for the officers of this Society for 1908, have the honor to report as follows:

Total number of ballots cast	413
Number of ballots rejected as irregular	13
Number rejected as not qualified to vote, on account of non-payment of dues	4
Total number of ballots counted	396
Number of votes cast for President:	
Andrews Allen	189
C. F. Loweth	199
Number of votes cast for First Vice President:	
J. W. Alvord	379
Number of votes cast for Second Vice President:	
P. Junkersfeld	363
Number of votes cast for Third Vice President:	
D. W. Mead	257
P. B. Woodworth	106
Number of votes cast for Treasurer:	
Albert Reichmann	373
Number of votes cast for Trustee for three years:	
L. E. Ritter	378

(Signed) Thos. R. Cummins,
H. M. Morse,
Ernest F. Smith.

Treasurer's Report for the Year Ending Dec. 31, 1907.

January 2, 1908.

To the Board of Direction, Western Society of Engineers, Chicago.

Gentlemen: I respectfully submit herewith, a statement of the Treasurer's account for the year ending Dec. 31, 1907, as follows:

Cash Statement.

Jan. 1, 1907, cash in bank subject to check		$ 1,018.10

Receipts.

Dues	$8,970.35	
Entrance Fees	1,358.00	
Subscription to Journal	397.89	
Advertising	2,662.78	
Sales Journal	93.20	
Interest	750.65	
Journal account	29.50	
Library account	28.15	
House expense	307.50	
Sta. Postage and Exchange	23.63	
Chanute Medal Fud Account	25.00	
General Printing	235.08	
Furniture and Fixtures	30.00	
Investments	1,000.00	
Arnold Fund	1,000.00	16,911.73
		$17,929.83

EXPENDITURES.

Journal Account	$4.579.48		
Library Account	787.86		
House Expense	2,860.29		
Sta. Postage and Exchange	741.08		
General Printing	1,073.65		
Services	1,640.00		
Furniture and Fixture Acct.	124.38		
Investment Account	4,997.80		
Interest Account	163.50		
Advertising, Commission	117.50	$17,085.54	
Dec. 31, 1907, cash in bank subject to check...		844.29	
			$17,929.83

SUMMARY.

Statement Jan. 1st, 1907.		
To Credit Western Society of Engineers	$ 7,079.10	
Chanute Medal Fund	1,149.00	
		$ 8,228.10
Investments	7,210.00	
Cash	1,018.10	
		$ 8,228.10
Statement Jan. 1st. 1908.		
To Credit Western Society of Engineers	$ 9,878.09	
Chanute Medal Fund	1,174.00	
*Arnold Fund	1,000.00	
		$12,052.09
Investments	11,207.80	
Cash	844.29	
		$12,052.09

*Gift of B. J. Arnold.

Respectfully, yours,
(Signed) ALBERT REICHMANN,
Treasurer.

SECRETARY'S REPORT.

CHICAGO, January 7, 1908.

To the Board of Direction, Western Society of Engineers, Chicago.

GENTLEMEN: Of the affairs of the Western Society of Engineers for the year 1907, I have the honor to report as follows:

Total membership in the Society December 31, 1907....1,000

Classified as follows:

Honorary members		1	
Active members:			
Resident	445		
Non-resident	336		
		781	
Associate members:			
Resident	61		
Non-resident	9		
		70	
Junior members:			
Resident	101		
Non-resident	47	148	
			1,000

This includes some members who have been elected but who have not fully qualified, and also sundry members who have tendered their resignations, to be effective January 1, 1908.

The number of new members elected in 1907, not counting transfers, was		136
Deducting losses in membership:		
Resignations	39	
Deaths	12	
Dropped	18	69
Leaves a net gain in membership of		67
Transfers in grade:		
Junior to Active	10	
Associate to Active	2	12

Deaths among our members in 1907:

Archibald R. Eldridge, Chicago, January 17th.
Harmon Trueman, Chicago, March 22nd.
A. MacArthur, Chicago, June 1st.
W. D. Hotchkiss, Chicago, June 3rd.
Nelson A. Sager, Chicago, August 30th.
James A. Lewis, Brooklyn, N. Y., September 1st.
John C. Darst, Chicago, September 5th.
Victor Hommel, Sandusky, Ohio, October 18th.
Storm Bull, Madison, Wis., November 17th.
Irving Parker, Chicago, November 17th.
Zimri A. Enos, Springfield, Ill., December 8th.
William S. Love, New York City, December 11th.

During the year 1907 there were 30 called meetings of the Society as follows:

1 Annual meeting.
9 Regular meetings, held on the first Wednesday of each month during the year, except January, July and August.
10 Extra meetings.
8 Meetings of the Electrical Section.
1 Smoker.
1 Ladies' night, held in Kimball Hall.

Also, there was an excursion to the University of Illinois, at Urbana.

A list of the meetings follows:

Tuesday, January 8th:

The 37th Annual Meeting (No. 593 of the Society) held in the evening in the rooms of the Mid-day Club in the First National Bank Building. Address of retiring President Mr. B. J Arnold and acceptance of the Presidency by Mr. W. L. Abbott.

Friday, January 11th:

The Regular and Annual Meeting of the Electrical Section, No. 21 (No. 594 of the Society). Mr. Ernest F. Smith, M.W.S.E., presented his paper on "The Development and Operation of a Large Electric Transmission and Conversion System."

Wednesday, January 23rd:

Extra Meeting (No. 595). Mr. H. M. North, of Cleveland, Ohio, presented his paper on "The Theory of Design of Railway Freight Terminals."

Wednesday, February 6th:

Regular Meeting (No. 596). Dr. H. Foster Bain, M.W.S.E., presented his paper on "A Review of the Work of the State Geological Survey."

Friday, February 15th:

Regular Meeting of the Electrical Section No. 22 (No. 597 of the Society). Mr. H. M Biebel addressed the meeting on "Direct Current Compensators for Balancing Electric Circuits."

Wednesday, February 20th:
Extra Meeting (No. 598). Mr. R. S. Kellogg of U. S. Forest Service, addressed the Society on "Some Problems in Wood Utilization in the United States."

Wednesday, March 6th:
Regular Meeting (No. 599). Mr. L. J. Hotchkiss, M.W.S.E., presented his paper on "Some Details of Reinforced Concrete Construction." Also Dr. W. Michaelis, Jr., M.W.S.E., presented his paper on "How to Prevent Failure in Concrete Construction."

Friday, March 15th:
Regular Meeting of the Electrical Section No. 23 (No. 600 of the Society). Mr. J. M. S. Waring of the Electric Storage Battery Co., read his paper on "The Application of the Storage Battery for Lighting, Power and Railway Service."

Wednesday, March 20th:
Extra Meeting (No. 601). Prof. L. P. Breckenridge, M.W.S.E., addressed the Society on "A Review of the U. S. Geological Survey Fuel Tests Under Steam Boilers."

Wednesday, April 3rd:
Regular Meeting (No. 602). Mr. R. M. Hosea, M.W.S.E., presented his paper (through the Secretary) on "A Colorado Mountain Reservoir."

Friday, April 12th:
Regular Meeting of the Electrical Section No. 24 (No. 603 of the Society) Mr. Thomas Lambert of Chicago Telephone Co. addressed the meeting on "Power Work as Related to Telephone Communication."

Wednesday, April 17th:
No meeting, but Saturday, April 20, "A Smoker" was held in the rooms of the City Club.

Wednesday, May 1st:
Regular Meeting (No. 604). Mr. R. H. Fernald of St. Louis, presented his paper on "The Present Status of the Producer-Gas Power-Plant in the United States."

Wednesday, May 15th:
Extra Meeting (No. 605). Prof. D. C. Jackson, M.W.S.E., (through his brother W. B. Jackson, M.W.S.E.), presented his paper on "Methods of Electric Lighting for Railway Trains."

Wednesday, May 29th:
Extra Meeting (No. 606). Mr. J. W. Schaub, M.W.S.E., read his paper on "The Railway Track of the Past and its Possible Development in the Future."

Wednesday, June 5th:
Regular Meeting (No. 607). Mr. Charles B. Burdick, M.W.S.E., presented his paper on "Methods of Pumping Deep Ground Waters."

Wednesday, June 26th:
Extra Meeting (No. 608). Mr. Isham Randolph, M.W.S.E., addressed the meeting on "The Work of the Sanitary District of Chicago Already Accomplished and yet Contemplated, South of the Controlling Works at Lockport."

Wednesday, September 4th:
Regular Meeting (No. 609). Prof. D. W. Mead, M.W.S.E., presented his paper on "Hydraulic Engineering at the University of Wisconsin."

Wednesday, September 18th:
Extra Meeting (No. 610). Mr. H. Kreisinger, M.W.S.E., presented the joint paper, by himself and Mr. W. T. Ray, JUN.M.W.S.E., on "The Nature of True Boiler Efficiency."

Wednesday, October 2nd:

Regular Meeting (No. 611). Mr. Horace E. Horton, M.W.S.E., addressed the Society on "The Design of Open or Latticed Compression Members; extension of detail specifications, for structural steel work to open compression members; the relation and proportion of parts forming a built channel of similar construction; also the lattice for same."

Friday, October 11th:

Regular Meeting of the Electrical Section No. 25 (being No. 612 of the Society). Mr. W. H. Crumb addressed the meeting on "The Determination of Telephone Rates for Large Exchanges."

Wednesday, October 16th:

Extra Meeting (No. 613). Prof. F. E. Turneaure, M.W.S.E., presented his paper on "Experimental Determination of Stresses in Web-plates and Stiffeners of Plate Girders."

Friday, October 25th:

Extra Meeting of the Electrical Section No. 26 (No. 614 of the Society). Prof. Leon Gerard of Belgium, addressed the meeting on "The Manufacture and Use of Ozone for the Purification of Water."

Wednesday, November 6th:

Regular Meeting (No. 615). Mr. A. S. Zinn, M.W.S.E., addressed the meeting on "The Culebra Cut of the Panama Canal."

Friday, November 8th:

Regular Meeting of the Electrical Section No. 27 (No. 616 of the Society). Mr. H. V. Allen representing Mr. W. D. A. Ryan of the General Electric Co., Lynn, Mass., addressed the meeting on "Color Value of Artificial Lights."

Saturday, November 16th:

Ladies' Night. Mr. J. W. Alvord, M.W.S.E., gave an informal talk, illustrated with lantern slide views, on "Camera Engineering Notes from Mexico." This was given in Kimball Hall, and refreshments were served after the lecture.

Wednesday, November 20th:

Extra Meeting (No. 617). Mr. Linn White, M.W.S.E., addressed the meeting on "The Construction of Small Parks in Chicago."

Wednesday, December 4th:

Regular Meeting (No. 618). Mr. George B. Springer, M.W.S.E., addressed the meeting on "Tunnels Under the Chicago River for Electric Cables."

Friday, December 13th:

Regular Meeting of the Electrical Section No. 28 (No. 619 of the Society). Mr. D. W. Roper, M.W.S.E., addressed the meeting on "A Few Unusual Burnouts in Underground Cables."

Wednesday, December 18th:

Extra Meeting (No. 620). Mr. A. Bement, M.W.S.E., presented his paper on "Some Results Due to Improvement in Boiler and Furnace Design."

During 1906 amendments to the By-Laws, increasing the Fees and Dues, were submitted to the membership and approved, as shown by the letter ballot. This increase, which began in the past year of 1907, has not seemed to have any objectionable effect on the growth or interests of the Society.

During 1907 other amendments to the Constitution and By-Laws were submitted to the membership by letter ballot, and have been approved. These relate to the age limit of Juniors; to the form and action of the admission to the Society, and to the creation and composition of a standing committee on amendments. These amendments were voted on at the end of 1907 and became effective with the beginning of the year 1908.

Very respectfully submitted,

J. H. Warder,

Secretary.

LIBRARIANS REPORT.

CHICAGO, January 7, 1908.

To the Board of Direction, Western Society of Engineers, Chicago.

GENTLEMEN: The Librarian begs to submit the following report on the Library of the Society:

Number of books accessioned up to December 31, 1907	6,583
Number of books accessioned up to December 31, 1906	6,103
Additions to Library during 1907	480
These may be classified as follows:	
Number of volumes of serials bound by the Society	163
Number of volumes of bound books,—gifts and exchanges	202
Number of volumes of bound books bought by the Society	99
Number of pamphlets accessioned	16
	480
The total charge against the Library for 1907 is	$787.86
Deducting sundry returns to the Library Account	28.15
Leaving the net charge against the Library	$759.71
Classified as follows:	
Services	$331.50
Books purchased	224.47
Binding of books	181.75
Sundries	21.99
	$759.71
To this might be added the account of Furniture and Fixtures for 1907	119.38
Total	$879.09

Very respectfully submitted,

J. H. WARDER,
Librarian.

BOOK REVIEWS

GOLD DREDGING. By Capt. C. C. Longridge. Mining and Consulting Engineer. Second and Revised Edition. 1907. London. The Mining Journal. Cloth, 6½ by 9½ inches. 339 pages; many illustrations. Price 20s net.

The second edition of this valuable work on gold dredging is most welcome; the plan of issuing annual supplements to the original volume of 1905, as announced in last year's supplement, has evidently been abandoned. Undoubtedly in a work of this kind it is better that there should be a complete revision, as in this present volume, even if issued less often.

The author has rearranged his divisions of the subject, each presented in a separate chapter; has added extensively to some chapters and introduced new ones, as well as many illustrations to the already numerous number of the first edition. As to the many photographic pictures of dredges at work, these are of great interest and practical value in showing real conditions.

The chapter on the dipper dredge is extended to include a recent Alaskan experience, which appears to have been somewhat successful mechanically, but at a high yardage cost for the dredging.

The suction dredge, it would appear from the examples cited, is unsuited to cemented ground, or coarse material. It is very doubtful in the reviewer's opinion if it can ever become really competitive with other gold dredging machines. The conditions required for successful working are too rarely found.

The submerged jet dredge is introduced in a new chapter; it is reported as experimentally successful in New Zealand.

As in the first edition, the largest part of the volume is devoted to the bucket dredge, which is the successful and almost universal kind used for gold dredging.

Some addition is made to the previous discussion of the relative merits of the New Zealand and California types; the latter have much larger capacities and are of a heavier construction. There is also some difference in the gold saving apparatus, and in the method of handling the dredge. The author does not take sides, but considers that each may be best suited to the conditions it has to meet. The former types he states "have been largely supplanted by the modern American dredge, which embodies many features of New Zealand practice."

The disposal of tailings with reference to preventing damage to agricultural lands further down stream, has been more fully gone into and California experience cited.

A certain scheme tried in New Zealand, is described where the top soil is successfully stripped and redeposited on top of the gravel tailings. Where natural conditions admit, this seems like a simple and highly desirable thing to do.

The chapter on working costs has been extended; figures are quoted from American practice, as well as New Zealand.

The descriptions of likely gold dredging ground throughout the world have been greatly extended; as these descriptions are gathered from all kinds of sources, the author wisely cautions the reader "to seek competent advice before operating in any field." However, it would appear that the world possesses a vast amount of gold bearing gravel, widely distributed, but presumably comparatively little of it is available with present dredging methods and costs.

It will be noted that the author includes in his book descriptions of some mechanical excavators and machines, like the dry placer machine and the bottomless scraper. While the information is interesting, it does not seem to have a place in a work on gold dredging—which in the ordinary acceptance means work proceeding from floating platforms. To cover this the author enlarges his former title, but on the other hand, there are many other forms of mechanical excavators than those which he describes. In the opinion of the reviewer such interjections tend to diffuseness. If desirable to include such information in a book like this, which aims to be a standard work on gold dredging, it would seem best to put it into a supplement.

As in the first edition, the indexing is complete and excellent.

As a whole the new edition is very satisfactory and will be valuable to those interested in gold dredging. G. S. R.

Economics of Railway Operation. By M. L. Byers, Chief Engineer, Maintenance of Way, Missouri Pacific Railway. New York. The Engineering News Publishing Co. Cloth; 6 by 9 inches; about 700 pages; many figures, diagrams and forms illustrating the best recent practice. Price $5.00 net.

This work which has just been published, covers the railway operating field very thoroughly, giving us all food for thought in this age when railway corporations are so distinctly in the limelight. The author divides his treatise of 700 pages into seven parts.

The first part, the organization of a railway system, is set forth and by diagrams is shown a working force for a railroad 300 miles in length, for 1,200 miles in length, and also one for 6,000 miles in length; and a diagram showing the organization of the Pennsylvania Railroad System, considered a standard throughout the world—(some additions have been made to this latter organization since this compilation). The author draws from the Departmental and Divisional systems of railroad organization to form his ideal system. The Divisional system we think preferable in some cases where the mileage is large and covers a much elongated territory, such as the Harriman system. There is given in detail the by-laws and organization for conducting the affairs of a railroad corporation. The duties of each official and employee

are stated and to whom each reports; also general rules and regulations are given in detail.

Part two, takes up the subject of employment, education and discipline of forces, and dwells on the requirements for obtaining service with the company; the merit and demerit system; insurance and pension departments, and the plan of employees becoming stockholders in the company on the installment plan, such as carried out by the Illinois Central R. R., Great Northern Ry., and the U. S. Steel Corporation.

Part three, deals with the accounting department, giving in detail the system to be employed in taking care of the receipts and expenditures of a company, freight and passenger; and revenues from other sources, such as from investments and real estate. The accounts are named and numbered and the manner in which these are carried on the books of the company are given in detail for the several departments.

Part four, gives a list of standard forms to be used for the necessary reports that pass between the employees and officials in conducting the routine business of the company: M. W. reports, freight and passenger reports, etc. These reports simplify the methods and cut down the letter correspondence to an economical basis, and systematize the office and field work. Many samples of reports are given.

Part five, deals with economic operation of the several departments of the Railway: the Maintenance of Way, Machinery, Transportation, Freight, Passenger, Purchasing, Law and Treasury. The operations of each of these departments are studied, argued and discussed in great detail and with intelligence, suitable examples being cited whereon to base an economic decision or result. Reports from well known railroads are given and analyzed. The facts deduced therefrom can be applied with necessary minor changes to any railroad system, and rules, regulations and forms applied thereto for its economic operation.

Part six, contains anaylses of operations and expenses, and gives samples of balance sheets of operating expenses, statements of ton-miles, of freight hauled and tables showing delays to trains and their causes and remedies.

Part seven, treats of betterments, roadway improvement, grade reduction, shortening of line, and improvements to terminals, increase of locomotive capacity, etc., in order to obtain more economic results; that is, greater net earnings which is what the stockholders wish. Throughout this entire work, facts can be gleaned which will enable all operating officials to consider whether their systems are being conducted on the most economic basis in all departments. As Wellington has given us his well known book on "Economics of Railway Location" (which we all have pondered over more or less, and which to this day is a standard for teachers and practitioners), Byers now comes forward with this complete work on "Economics of Railway Operation," which should surely commend itself to all who follow the railroad business, and to those who are teaching and studying railroad engineering.

J. C. G.

Specifications and Contracts. By Dr. J. A. L. Waddell and John Cassan Wait. New York. Engineering News Pub. Co. Cloth; 6 by 9 inches; pp. 169. Price $1.00.

The authors of this little work need no introduction to the general engineer yet it will do no harm to say that Dr. Waddell is an engineer who has a great reputation as a consulting civil engineer, making a specialty of bridge work and who for a long time held an important teaching position in Japan. Upon his arrival in the United States he proved himself a controversialist of high order and his influence has been strongly felt in contemporary bridge design. No matter what differing opinions exist and may be expressed, he is one of America's great engineers. Mr. Wait was educated as an engineer and had considerable experience both as a practitioner and as a teacher. While teaching engineering in Harvard he became interested in the legal side of the profession and took a law course. He is now a lawyer in New York holding a

high position in the city government. A few years ago he gave to the world two large volumes dealing with the law of engineering and architectural operations. These books are now standard treatises on the subjects discussed. That this lawyer, a member of the Am. Soc. C. E., should join with an eminent civil engineer in the production of a book on specifications and contracts is a guarantee that the book should be worth the price charged.

The low price is explained by the authors who say that the book is intended primarily for students in engineering schools and should be an inducement for all to buy. The book consists of a course of lectures delivered by Dr. Waddell to the students of Rennsalaer Polytechnic Institute, Troy, N. Y., and other schools. There were two lectures in the course, one on contracts and the other on specifications. To these have been added notes making it better suited for text book use in which the students are exercised in contract writing. The final chapter is by Mr. Wait and deals with the legal principles involved. This constitutes a brief and valuable treatise on contract law.

The reviewer considers this an extremely good work for engineering students. However, it will require an interested teacher to use it in class work, for it might be vastly improved in arrangement for text book purposes. It is written in a most pleasing style so it will be appreciated by experienced engineers and contractors. Subheadings are arranged in prominent type on the page margins so any desired point may be quickly found. The chapter by Mr. Wait is decidedly the best part of the book from the standpoint of the man who has had considerable experience with legal quibbles over contracts. The book is well worth buying and does far towards filling a gap in engineering literature.

E. McC.

THE METRIC AND BRITISH SYSTEMS OF WEIGHTS, MEASURES AND COINAGE. By F. Mollwo Perkin, Ph.D., Head of Chemistry Dept., Borough Polytechnic Institute, London. The Macmillan Co., New York. Cloth; 8½ by 5½ inches; pp. 83; 17 diagrams. Price 50 cents.

Professor Perkin of the Borough Polytechnic Institute of London, has written a little book to enable students to obtain a mastery of the metric system of notation. In the introduction he advances the usual arguments in favor of the system, these being principally its simplicity and saving of time, as well as the hope of increased trade with other nations who have adopted the metric system, while he only refutes cursorily the arguments which have been brought against it, such as the great expense to manufacturers to change their standards and tools, and the confusion which is likely to result in many trades. He then devotes a separate brief chapter to measurements of length, of areas, of weights, of volume, of specific gravities, of measurements of temperatures, and finally of money, with tables, diagrams and examples. An appendix supplies further information.

The book is well written and will be useful to students, as well as to those who promote legislation to make compulsory either the use of the metric system or of its teaching in every school in the land.

O. C.

HOW TO READ PLANS. By Charles G. Peker, Editor "Woodworkers' Review." New York. Industrial Publication Co. Cloth; 7½ by 5 inches; 46 pages; 43 drawings in text, 8 large folding plates. Price 50 cents.

Each subject is taken up, explained and illustrated separately; then a full and complete set of architect's plans for a frame house is taken up and explained so the reader will be sure to understand how to read plans.

The useful suggestions, hints, etc., in this book will make it of value to even those who understand how to draw, as well as those who do not.

SWEET'S INDEXED CATALOGUE OF BUILDING CONSTRUCTION, for the years 1907-1908. Architectural Record Co., 11-15 E. 24th St., New York. Cloth. 13¼ by 10 inches; in two volumes; pp. 1,402; illustrated.

The publishers of this work have undertaken to group together the various trade catalogues of building materials and building material firms, and expect

to issue a revised edition every year. There is included a very complete cross-index covering 145 pages and comprising over 10,000 separate entries, which will be of value to those looking for information.

"Where Water and Fuel are Scarce or Dear" is the title of an interesting circular treating of the heating and purifying of boiler feed water in mining and smelting plants. The pamphlet is published by the Harrison Safety Boiler Works, 3188 N. 17th St., Philadelphia, Pa., and shows that by means of a Cochrane Heater, about 6½ lbs. of water may be heated from 60 to 210 deg. F. by 1 lb. of exhaust steam, and further that the 1 lb. of steam will be condensed and added to the boiler feed as pure distilled water, thereby saving 16 per cent of the coal bill as well as a nearly equal proportion of raw water. Also, heating the water throws out of solution the bi-carbonates of lime and magnesia, which, along with mud, sand and other impurities, are precipitated in the heater instead of being carried over into the boiler. It is pointed out that as the heater does part of the work of the boilers, six boilers and a Cochrane heater can make more steam, while requiring less fuel, less labor and less water, than seven boilers without the heater.

This pamphlet will be of interest to all who own or operate boiler plants.

LIBRARY NOTES.

The Library Committee wishes to express thanks for donations to the library. Back numbers of periodicals are desirable for exchange and in completing valuable volumes for our files.

Since the issue of the JOURNAL for December, 1907, we have the pleasure to report the following additions to the library and gifts from donors named:

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Cir. 128. Preservation of Piling Against Marine Wood Borers.

Cir. 130. Forestry in the Public Schools, Winkenwerder.

Cir. 131. Practical Forestry on a Spruce Track in Maine, Cary.

Cir. 132. Seasoning and Preservative Treatment of Hemlock and Tamarack Cross-ties, W. F. Sherfesee.

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Cir. 134. The Estimation of Moisture in Creosoted Wood, A. L. Dean.

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Cir. 137. Consumption of Poles in 1906.

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Plant of the T. B. Laycock Manufacturing Co., Indianapolis.

Journal of the
Western Society of Engineers

VOL. XIII. APRIL, 1908. NO. 2.

LOCATION, ARRANGEMENT AND CONSTRUCTION OF MANUFACTURING PLANTS

By George M. Brill, M.W.S.E.

Presented March 4, 1908.

The subject of manufacturing plants is so broad, complex and diversified that it must not be assumed that all which might be said about the possible combinations of requirements and manner of fulfilling them will be covered in a paper of this kind, or that the applications to any specific case will be exhausted. However, an endeavor will be made to touch upon some of the important features which control in all that pertains to a large variety of manufacturing plants. In taking up the building of a new manufacturing plant the controlling elements and the questions which naturally arise are largely included under the headings of Location, Arrangement and Construction.

There are many conditions which influence the selection of a site for a manufacturing plant and while the object of this paper is to consider the matter from an engineering and construction standpoint, a word might be said in passing regarding the commercial considerations which frequently have a bearing upon the subject. An endeavor is often made by the real estate man to influence the manufacturer's selection in order to advance his own interests or for the purpose of promoting a town or land scheme, with little regard for the actual requirements or the adaptability of the location, size or facilities. The manufacturer is not unnaturally influenced and perhaps even led to neglect the more important factors by the attractiveness of cheap land or a bonus offered by interested parties. The success of the business depends to a considerable extent, larger than usually appears, upon the fitness of the location and its adaptability to the needs of the business, and the short life of some concerns has been due to the unsuitability of the location and size of the site selected.

For the purpose of this paper these ulterior factors may be disregarded, especially since there are enough legitimate ones which deserve careful consideration in order that the present and future requirements may be met.

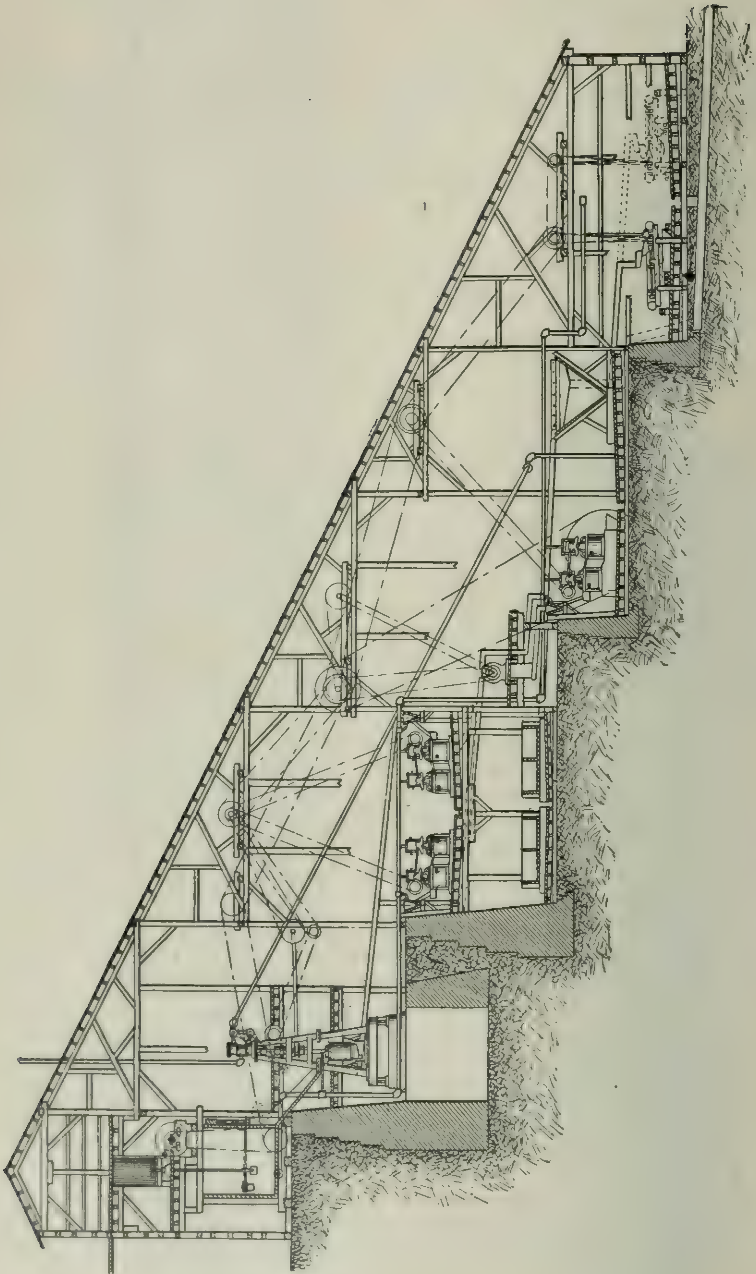

Fig. 1.—Concentrating Plant, Showing Advantages of Sloping Site.

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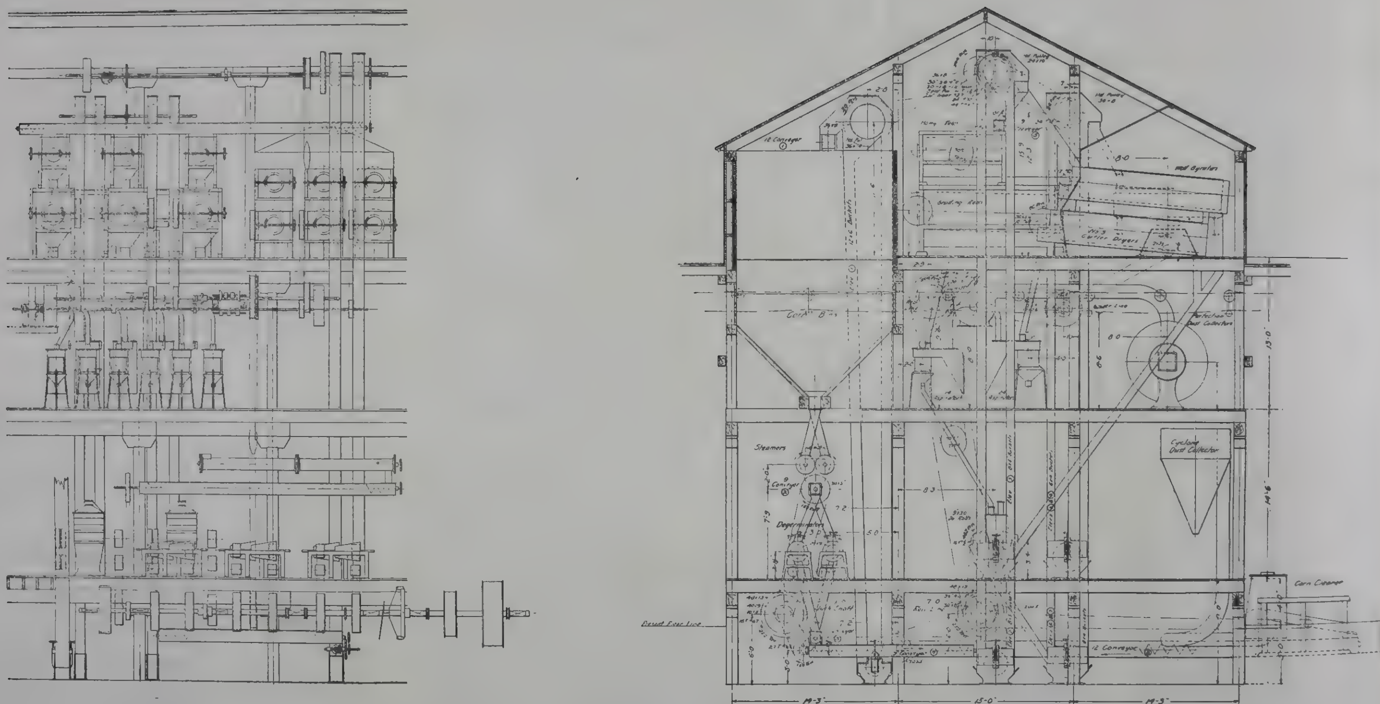


Fig. 2.—Corn Degerminating Plant, Showing Elevators, Conveyors and Chutes.

It frequently occurs that some sacrifices are necessary in the location, size and character of sites in order to properly meet such fixed conditions as source of raw material and fuel or the necessity for an abundant supply of water. While these have their influence and must be given due weight in connection with all plants in which they form controlling factors, it may be sufficient to simply refer to them here.

The location of a site is governed largely by the amount of land required, its shape and topography, transportation facilities, the supply of labor and to some extent by the character of the soil.

The amount of land depends upon the size of the plant to be built and the probabilities of future growth. By size of plant is meant the area occupied by the buildings, the necessary or desirable space about them and the yard room required for the storage of raw materials and finished products.

The required shape of a site is controlled by the character of the buildings, their logical relative location, the receiving and shipping requirements and whether they are met by the use of railroads, teams or both and especially by the necessary manner of getting tracks to and about the property to conveniently serve the several needs.

The topography of the land may become an important factor in determining the site best suited for a specific case, especially where the character of the materials and the processes employed are such that gravity methods of handling can be advantageously used. Some processes can be performed to the best advantage on one level, but in many cases it is not only convenient but essential to have several ground floor levels. This often arises from the character of the materials treated, methods of handling them, machinery used and the necessity for heavy foundations reaching well into the ground. Sometimes the operations are facilitated by having railroad tracks extend into the buildings at two or more levels.

The transportation facilities involve not only the local receiving and shipping connections, but those desirable on account of the character and sources of raw materials and the centers of distribution and consumption for the finished products. The need of direct water transportation for manufacturing plants is so comparatively infrequent that it can be practically neglected. Where the nature and requirements of the business are such as to make it essential, other naturally influencing conditions may have to be compromised. The handling of large amounts of heavy and bulky materials or the use of large quantities of fuel may also tend to fix the general location within narrow limits.

The manner in which the needs for labor will be met is usually determined by the character, number and magnitude of other manufacturing interests located in the same town or in the immediate vicinity. It is not generally found difficult for a new concern locating in any section to procure, within a reasonable time, all the labor necessary, unless the new plant is of large magnitude or the requirements are for skilled labor of an exceptional character. Upon the

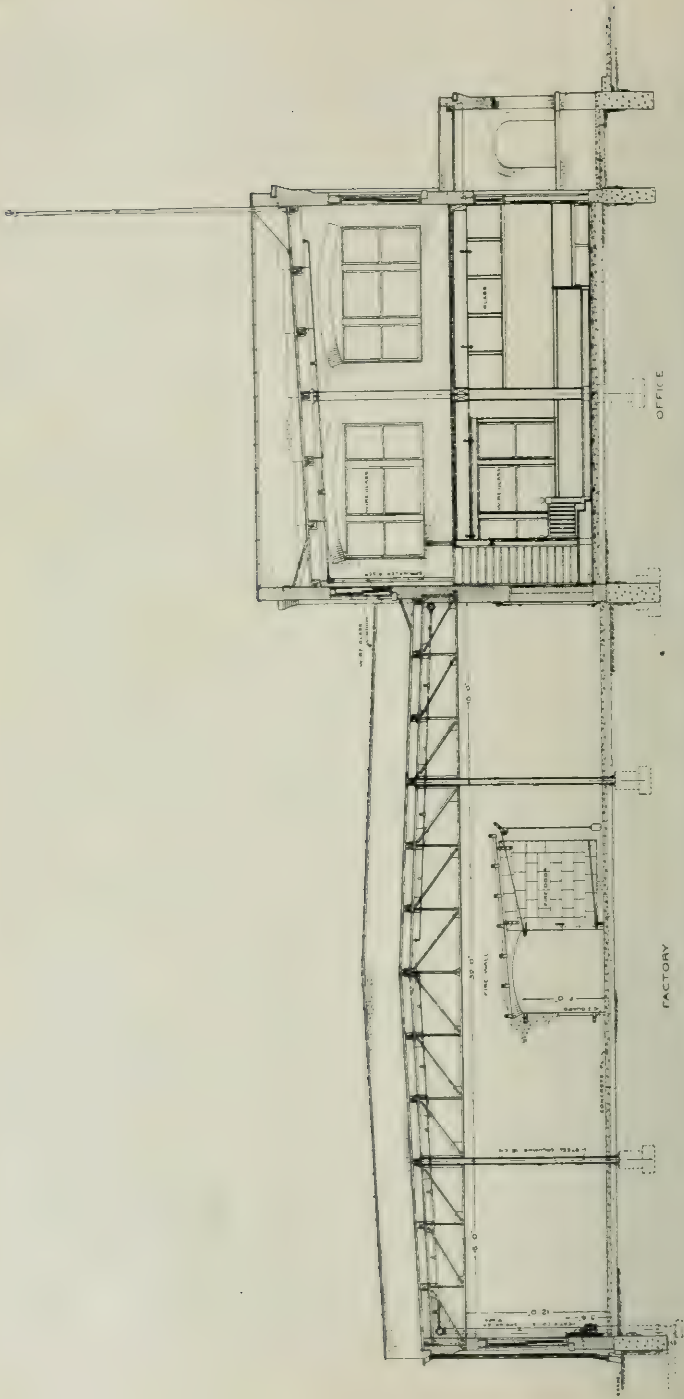
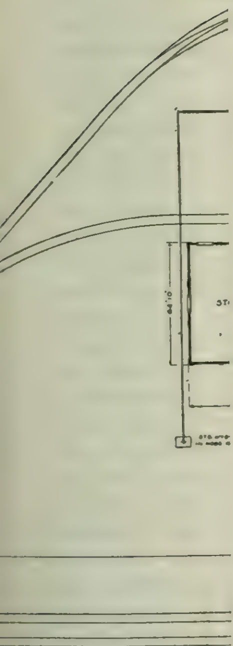


Fig. 3.—Sectional Views of One Story Factory for Manufacture of Metal Refrigerators.



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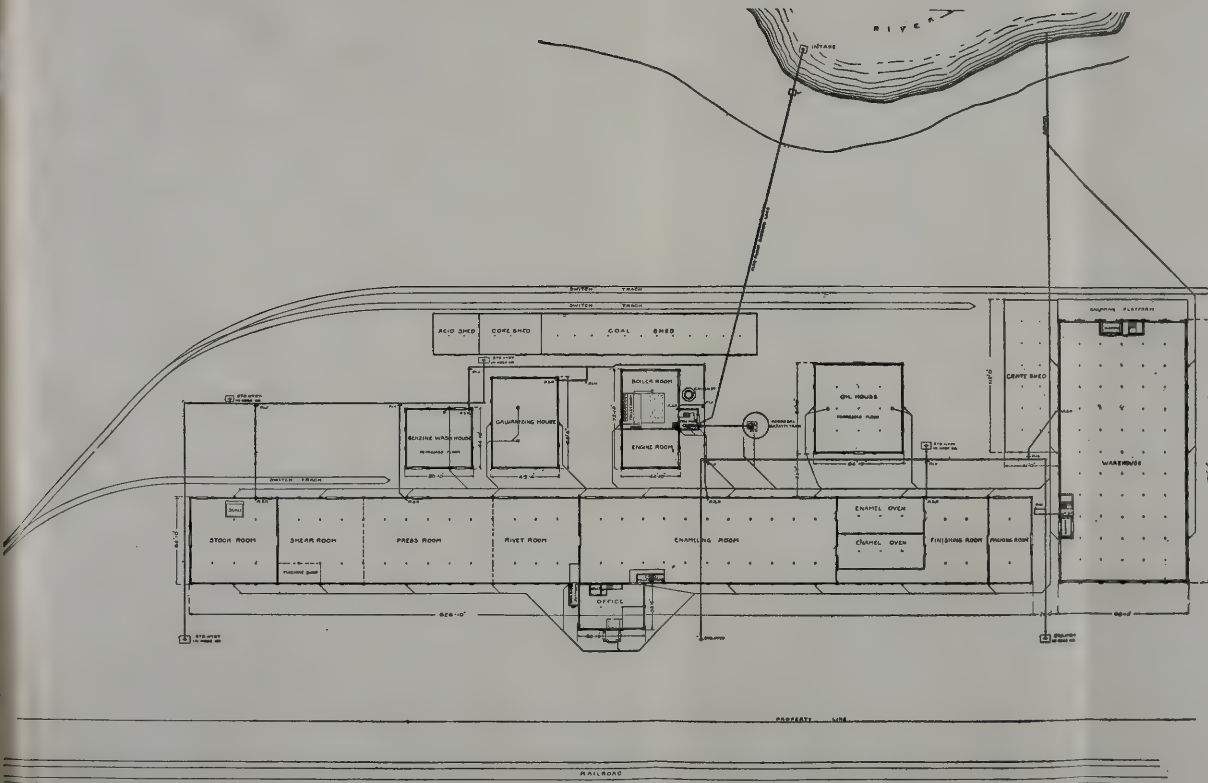


Fig. 4.—General Plan of Plant for Manufacture of Metal Refrigerators. A One-story Factory, Making One Line of Bulky Goods.

advent of a new industry there is usually a gradual readjustment of the labor conditions and all ordinary demands are met. The labor problem is a reason for a tendency towards communities of manufacturing interests of the same general character, although of course the labor requirements may not be the only reason for such tendency. In connection with the location of a plant due consideration should be given to the cost of living and the means of cheap transportation between the site proposed and the local centers of population.

The processes involved in all manufacturing plants and the co-relation of the departments or what can be called the plant geography are so completely engineering matters that before selecting the site for a new plant an engineer should be engaged. He should be capable of grasping the whole problem, experienced in building materials and construction and competent to execute the work in a thorough and practical manner, recognizing not only the influence of the manufacturing processes upon the arrangement of the buildings, but the types and details of construction best suited for the needs. He should be unhampered by any commercial connections.

Although a manufacturer usually knows what he wants to accomplish, he is often handicapped by lack of time and experience to work out the problems. The examination of a large number of plants indicates that in a majority many of the important factors controlling productive economies have not received due consideration. If a manufacturer has had experience in a plant which he proposes to replace or extend, his time in conjunction with that of the designing engineer can be well spent in carefully reviewing the growth and development which has resulted in the present conditions, and with this information and data before them consider and decide upon the present needs, how much space should be provided for growth in the initial construction and what provisions should be made for extensions when they become necessary. Convenient means of extending the buildings is important, for obstructions cause sacrifices of the original or compromises in the future construction. Unless care is exercised in the original plants it is difficult to make any material changes without interruption to the operations and loss of revenue. The possibility of changing the uses of the building from those for which they are designed should be kept in mind. The use of an old plant as a guide materially assists in determining the space and shape required in the new, emphasizes the good features and helps to avoid the bad ones. Without having the benefit of an old plant, the engineer in co-operation with the manufacturer, should obtain all the available information bearing on the methods and processes contemplated. In reviewing and studying the general scheme of manufacture, the methods which have been used should be carefully considered, all meritorious features given due weight and an effort made to improve them in the new undertaking. After thoroughly familiarizing himself with the problem, the engineer should lay out several general arrangements of plants in which the processes can be carried out advantageously. This treat-

ment of the problem will indicate the relative importance of the different departments and how they should be located in relation to each other; it will bring out the means which must be employed in the different arrangements for handling materials in course of manufacture and the effect each scheme may have on the power transmission; it will develop the uses and distribution of water and emphasize the important subject of sewerage and drainage. This study will also bring out the receiving and shipping requirements, the needs for storing raw materials and finished products, the portions of the buildings to be reached by railroad tracks and the most desirable location for the power plant.

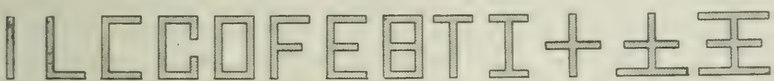
If large quantities of water are used, making the problem of waste

Fig. 5.—Interior View of One-story Building, Showing Natural Lighting, With Lantern Roof Construction.

disposal important, due consideration must be given to the requisite means of handling the drainage without its becoming unduly expensive. Tracts of land available for manufacturing purposes are sometimes located long distances from city sewers or other drainage facilities, or the character of the waste may make it objectionable in sewers or streams into which the sewage ordinarily would be led. There may be a dry refuse for which adequate removal or dumping provisions must be made. One of the common mistakes made in the location of plants is the neglect of these important matters. The power needed and whether or not the general requirements are such that the engines are to be operated condensing should be considered in connection with the water available and its cost. It may become necessary in some lines of manufacture to be governed somewhat in site selection by the necessity for pure air.

Due consideration of all these important matters and a careful comparison of the merits of several possible plant arrangements should lead to the adoption of the most suitable one and help determine the site to be selected.

The arrangement of buildings together with the size and number of stories should be determined largely if not entirely by the manufacturing processes, except where they involve undue fire risks. All methods to be employed for conveying and transporting materials and products should be developed and proper consideration given to any effect they may have on the relative position of the departments and the building construction. If the nature of the products is such that the raw materials can be carried to the top floor of a building several stories in height and then in general be worked towards the ground floor, as the several processes are completed, the tendency would naturally be towards a building of that character. To handle goods in course of manufacture in this manner involves the use of elevators, chutes and conveyors in some of the wide variety of types made, and the adaptability of this apparatus permits of a large range of materials and products being satisfactorily and economically handled. However, in many cases, the parts in process and the products are so cumbersome or heavy and involve so many operations in their production that it is not practicable to handle them in this manner and this would tend towards the use of one story buildings. Where the parts are small and handled in large quantities, the shape and arrangement of the building or buildings may have little influence on the economy of the operations. If but one line of goods is produced and the raw materials and parts are such that they are carried along together, a rectangular building may serve the purpose quite as well as one of more complicated shape. It sometimes occurs that an article or machine forming one of the products is assembled in one place by bringing together parts produced in many portions of the plant, when other than rectangular buildings may be more suitable. Such shapes should be considered as indicated by the forms below. These show various evolutions in shapes.



By the use of such forms, materials and parts may travel from two or more directions and pass through the respective processes on their way towards final assembling, or several lines of goods can be made and without interference brought to a common point for storage and shipping. At the same time, with these forms of structures sufficient space can be provided between and about the several parts so that each will be accessible to track and yard facilities and readily provided with natural light. With the original construction properly located on the site these forms can be extended and departments readily added.

It often happens that a group of several detached buildings may best serve the purpose. This may be emphasized by the size of the plant or the manufacture and storage of parts in large quantities before assembling Especially is this true if, because of the sizes and character of these parts, they can be stored in an open or covered yard as well as to use more valuable space in the plant proper where they might form obstructions in the movment of the materials.

To determine the best form and arrangement of buildings, the logical method of procedure is to decide upon the space to be allotted to each department and their co-relation and to consider the several processes, the character of the materials, the sizes of parts, the amount and nature of the work to be done and the requirement for light.

Fig. 6.—Concrete Building, in Process of Construction.

This will indicate the best unit width of buildings and, with this fixed, the total length which will result by the use of one, two or more stories will be shown. The relation of the several steps in the process of manufacture will determine where the different departments should be located and thus to a large extent make clear the number of stories which will most naturally meet the manufacturing requirements.

The ground area covered is directly dependent upon the number of stories for a given total floor space, therefore the relative merits of two or more available sites, with areas differing enough to influence the building arrangements, should be weighed against those of buildings constructed with various numbers of stories. Not only the areas of available sites, but their unit costs might influence the height of the buildings and the shape of the plat may also modify the form of the buildings. To get the most efficient results it is essential to have land of sufficient quantity and of such shape that the

building arrangements need not be compromised and thus leave the designer free to adopt such forms and heights as may best suit the processes and space requirements.

If several kinds of raw materials are received on cars in sufficient amounts to make it necessary or desirable to reach different portions of the plant with tracks, due attention should be given to the manner of bringing them onto the premises and of reaching the objective points—shipping and receiving—in such a way that the tracks will not be objectionable or interfere with such other means of outside communication between the buildings as surface and overhead tramways, runways, etc.

If a unit width of not to exceed 60 ft. is adopted for buildings two

Fig. 7.—View of Completed Concrete Building, Shown in Fig. 6.

or more stories high, natural light can be obtained suitable for most manufacturing operations. Where a portion of them require exceptional natural light they can usually be performed on the top floor of buildings, when, by the use of a saw tooth roof, the best lighting conditions will result. Where all the operations require light of exceptional quality, it may become necessary to resort to one story buildings covered entirely with a saw tooth roof, although a good lantern design adequately meets all but the most exacting needs.

Considering the same general character of construction and a given amount of space, buildings of one story are generally somewhat more expensive than those of a greater number. This is emphasized if the value of land is taken into account. Eliminating all variable details, as far as practicable, it is still necessary to have such essential features as roofs and foundations whether the building are one or more stories and a unit area of roof costs no more when covering several stories than when covering one. A floor is chargeable to each story, but as they increase in number the roof expense for each is

reduced. The foundations are also more expensive per unit of floor area in one story construction, for while they would be somewhat lighter than where supporting several stories, there is but little difference in the cost of excavating and the cost of forms does not increase in proportion to the number of stories. The comparison of costs in general would be affected by the loads for which the floors are designed, heavier loads tending towards one story construction.

Careful study should be given to the heights of stories and where there are several they may vary to meet the requirements of the operations which take place in them. However, the heights in any case are controlled largely by the unit width of building, the apparatus which will be installed, the methods of transmitting power and the character of the materials passing through the several departments. To minimize the waste of timber the market lengths should fix the exact heights and the size of bays.

In determining the width and deciding upon the general type of buildings to be constructed, as governed by the department requirements, due attention must be given to the resulting size of rooms and the manner in which they can be assembled so as to provide fire walls at logical points and to keep the areas within the specifications of the insurance underwriters.

The convenient location of space for the temporary storage of raw materials and manufactured parts is important in promoting economy in production. Coarse and bulky materials such as lumber, castings, steel, fuel and other stock may well be placed conveniently accessible to the several departments using them. Manufactured parts should be stored as near the path of travel of the goods in process as practicable, but if large numbers of small parts are used, making the unit expense for handling very small, this is not so important.

Basements of the proper construction afford useful space for the storage of a large variety of goods and should be considered favorably in the design of plants where the drainage conditions permit. The heights of car floors tend to fix the first floor level of many buildings and incidently about the same height is convenient for teaming. With the first floor fixed at this level buildings can be constructed with basements for a slight additional cost. To provide against frost, it is necessary to carry foundation walls from three to five feet below the surface of the ground. This depth with the distance up to the first floor added gives nearly the requisite height for the basement. Therefore, such space can generally be obtained for the expense of removing the soil and increasing the depth of the foundations. Dark basements are objectionable, often serve for the accumulation of rubbish and waste and are productive of fires through carelessness and negligence. With basements constructed so that nearly half their height is above the ground there is ample opportunity to obtain good natural light and good drainage can be provided at less expense because of the decreased depth. Space can therefore be provided which, being both light and dry, is well suited

for the storage of goods of almost any character, easily accessible and consequently desirable and convenient for use. While it may not be practicable, on account of the character and location of the operations, to store all heavy materials and parts in basements, the support which can naturally be provided for them should have some influence in arranging the departments at the time of making the preliminary study. Basements generally afford convenient space for carrying heating pipes, suitable provisions for which are often difficult or awkward to make when the first floor is on or just above the ground. Again many kinds of machinery which might naturally be placed on the first floor can be conveniently driven from below and thereby eliminate much of the transmission, with its objectionable features, from the working space.

Considering the types of buildings to be adopted there are two which fully meet modern requirements,—"fire-proof" and "mill" or "slow-burning." The former, as implied by its name, contains little or nothing in its construction of a combustible nature and is limited to structures of monolithic concrete and those with brick walls, with or without protected steel frames, and floors and roofs of concrete or tile.

The use of concrete for building purposes generally has not become sufficiently common to permit of a true and conservative comparison with buildings of better known construction. While concrete buildings for a specific purpose may have thus far cost more than those of first class mill construction, it is probable that with more general experience on the part of builders, and therefore improved methods and facilities and the natural competition which will follow, these conditions may materially change. It would appear at this time that with no local market influences affecting the cost of materials commonly used in building construction concrete may be used to advantage where the floor loads exceed 200 pounds per square foot. The reason for this tendency is apparent, for a considerable percentage of the cost of concrete construction is due to the cost of the necessary forms and the expense of handling them, which is but little greater for thick walls and floors than for thin ones.

The rapid development of the Portland cement industry in the last few years, together with the increased cost of other building materials has tended to make the use of concrete popular. Perhaps the novelty of it has influenced both engineers and laymen, but the tendency to use it for general building purposes has led many able engineers to give much careful thought and attention to the matter, resulting in much good work and many ingenious applications. It would seem that practically all possible forms of steel reinforcement have been used or suggested. Much progress has been made in the design and construction of concrete buildings and it is fair to assume that, with the experience naturally resulting from their construction and use, still further advancement will be made. There should be no question about the integrity of concrete buildings when high grade materials are used in the proper proportions, care is exercised in mix-

ing and when the concrete is properly placed and in accordance with suitable designs. Where the opposite of these conditions prevails disaster may be expected. Therefore, it is essential that each of these important factors—materials, mixture, and design, shall be right. There has doubtless been much poor cement used in the last few years and not all of that now on the market is as good as it should be. It is but natural to expect that in designs involving the use of new materials and new types of construction some mistakes will be made and in all probability such has been the case in this class of work. The principle sources of weakness, however, are probably due to the lack of uniformity of mixture and time allowed for setting. The elements of integrity in buildings of steel, brick, stone,

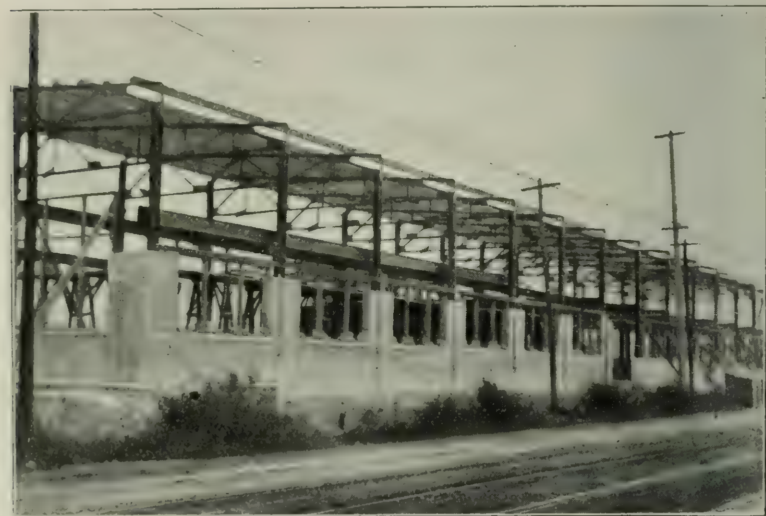


Fig. 8.—View of Building With Self-Supporting Steel Frame Work—During Construction.

wood, etc., are quite different from those which govern concrete buildings. In the former both the materials and workmanship are subject to effective inspection, while in the latter the materials and proportions are specified with care, but are usually mixed and placed by unskilled workmen after which, from its character, the work is difficult to inspect. The avarice of some contractors, who have been attracted to concrete building construction by its apparent simplicity and the consequent opportunity for poor workmanship and large profit, has resulted in much defective work.

There is a wide difference of opinion about the relative adaptability of concrete and the better known materials to buildings for manufacturing purposes. Where large bays are desirable concrete construction should attract favor, for with given floor loads fewer columns are required than where the floors are constructed of wood.

The method used for transmitting power and the character of the transmission machinery, the facilities required for attaching the machinery to the floors and the necessity for changing its location, would have a bearing on the use of concrete for manufacturing buildings. With electrical transmission and the use of motors coupled or belted to the machines or to the shafts driving groups of machines, it is seldom necessary to run belts through the floors and to provide openings for that purpose. With some classes of machinery it is desirable to drive from the under side by a shaft or motor located in the story below. Usually, however, where openings through floors are necessary for belts it is in connection with mechanical transmission, where the main lines of shafting are driven by heavy belts run-

Fig. 9.—View of Completed Building—Foundry and Machine Shop.

ning from floor to floor. It may be possible to anticipate the location of all openings necessary for this purpose, but in the actual construction and operation of plants many conditions arise which necessitate changes in the location of apparatus and the means for operating it. Openings also have to be provided in the original construction or made later through floors and walls for pipes, drains, wiring conduits, conveyors, etc., the location of the greater portion of which can best be determined as the plans develop and the several features of the plant are executed in logical order. It is hardly to be expected that the location of all openings can be determined before or during the building construction, in fact, it would be impracticable to either anticipate all of them or to so handle the transmission, piping and wiring as to make them fit a pre-arranged set of conditions. Such openings wherever made tend to destroy the fire proof feature which forms an essential consideration in the use of concrete buildings. Wood or steel strips can be placed in the floors for receiving lag

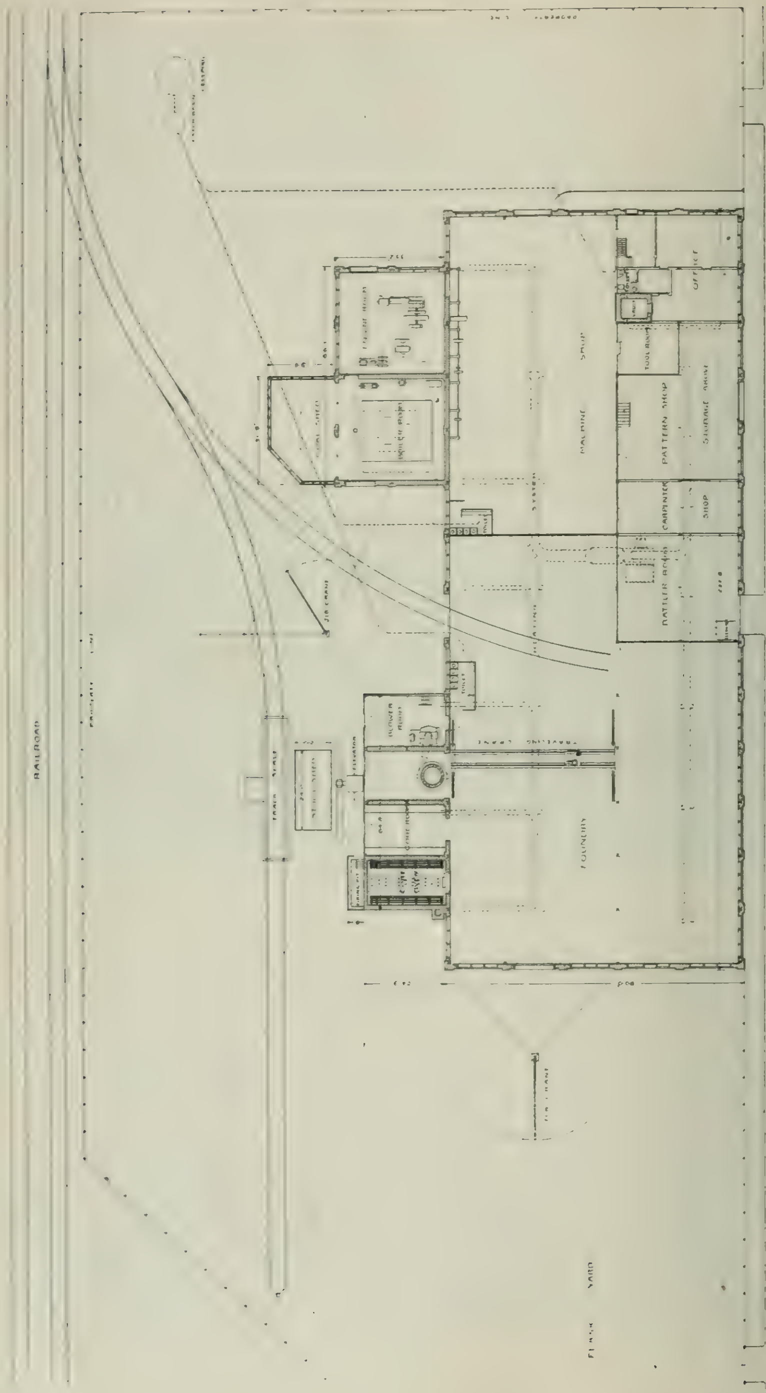


Fig. 11.—General Plan of Jobbing Foundry and Machine Shop.

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Fig. 10.—Sectional View, Through Foundry of Figs. 8 and 9.

screws or bolts to hold the machines in place. In a similar way shafting can be supported from ceilings, but to carry out these arrangements effectively the requirements must be known at the time of construction in order to suitably provide for them. If changes in location afterward become necessary, further provisions will have to be made. If all the requirements can be predetermined, the installation might be made with little or no inconvenience, but in practice the most carefully prepared plans are seldom carried out in all their details and those provisions which seem suitable and adequate are often subject to radical revision.

Comparing good mill construction with concrete, the former is much more adaptable to the various conditions and changing requirements in buildings used for manufacturing purposes. Concrete construction is admirably adapted for warehouses, where it is simply a matter of providing a given amount of space and floors which will support certain loads, especially where they are heavy.

Buildings constructed with self-supporting steel frames; brick, tile or concrete walls; tile, concrete or wooden floors and roofs are most suitable for certain classes of work and under some conditions and they approximate fire proof construction. Such buildings are especially adapted to the conditions generally found in shops, foundries and power plants, where large and unobstructed floor areas are requisite and traveling cranes are essential.

The "mill" or "slow-burning" type of buildings, though constructed to a large extent of combustible materials, is so designed and arranged that it is difficult for a fire to gain rapid headway. Buildings of this character are usually enclosed with self-supporting brick walls with columns, floors and roofs of wood. The columns and beams should have large cross sections with wide undivided spaces between them. The roofs and floors should be of plank, the former covered with a suitable roofing and the latter with a wearing surface of maple. The connections at the columns and the bearings in the walls should be so designed that the beams will be free to fall without causing the whole structure to give way. With the large spaces between beams, small pockets are avoided and fires which they would harbor are prevented because all parts are accessible to water from sprinkler heads or hose.

Buildings of mill construction have been found to be admirably suited to a large variety of manufacturing operations. With ordinary floor loads the construction can be such that bays of good size may be formed, large window openings provided and good light obtained, machinery readily fastened to and suspended from the floors and openings through floors easily made as required. Buildings of this type lend themselves so well to many manufacturing operations that changes can be made in the location of the equipment and departments or even other similar lines of manufacture substituted without materially impairing their usefulness.

Where stone or gravel is plentiful, concrete has come to be recognized as the most suitable material for foundations. This has been brought about to a large extent by the increased supply of Portland

cement and the greater cost of skilled labor necessary for the proper construction of stone foundations. With a small percentage of skilled labor, concrete foundations can be put in place rapidly and economically. It is to be expected that manufacturing plants will seldom be located where pile foundations are necessary. These cases are generally limited to locations adjacent to water, to made ground and where quick-sand is encountered. Where piles are used they should always be cut off below the water line and the foundations started from this level. In all cases where the buildings are of any considerable size or height and the foundations are to rest directly on the ground, borings should be made, reaching well below the level of the proposed footings of the foundations, and comprehensively cover the area in question. The evidence thus obtained should be carefully studied in order to intelligently determine the bearing values of the soil. This may also show that there is sand or gravel present which can be used for building purposes. In deciding upon the values to be used and the size of the footings for walls and columns, a thorough study and analysis should be made of the character of the loads to be supported. After providing for the weight of the building and other dead loads, it is not necessary to provide for the total live loads which come upon the several parts and for which they are designed, but the probable average.

By strictly observing the rules and requirements of the underwriters, the worth of the plant is increased. In order that the general construction may be such that all details shall be properly and effectively carried out to insure the minimum risk from fire and that all provisions for fire protection may be suitable and adequate, it is expedient that the designing engineer be conversant with the underwriters requirements. He should consider the character of the raw materials, the processes, the finished products and the methods of storage; and give due and proper attention to danger from fire which may be involved in handling any of the materials, executing any of the processes and not only reach a decision as to the type and character of the buildings to be built, but their construction and the materials to be used in them. The available water supply for fire protection purposes and adequate and positive means for procuring it in sufficient quantities are primary considerations in plant location as well as in the character of construction.

In locating the buildings, room should be left between them to prevent fire being communicated from one to another, and to afford adequate space in which to safely fight fires which may have gained headway. Buildings used for the manufacture and storage of highly combustible materials should be isolated, so that a fire in one of them will not endanger the plant. Oil houses should have their floors below the yard level in order that in the event of fire the burning oil would be confined to a restricted area.

Where the buildings are close together, or where flues are formed by light shafts and elevator or stair wells, openings in walls should be protected by wire glass which permits light to enter but obstructs the passage of fire. Where the admittance of light is not essential,

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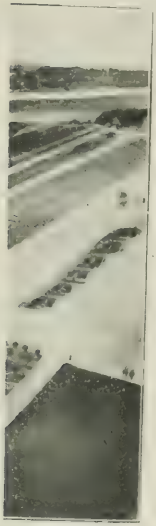

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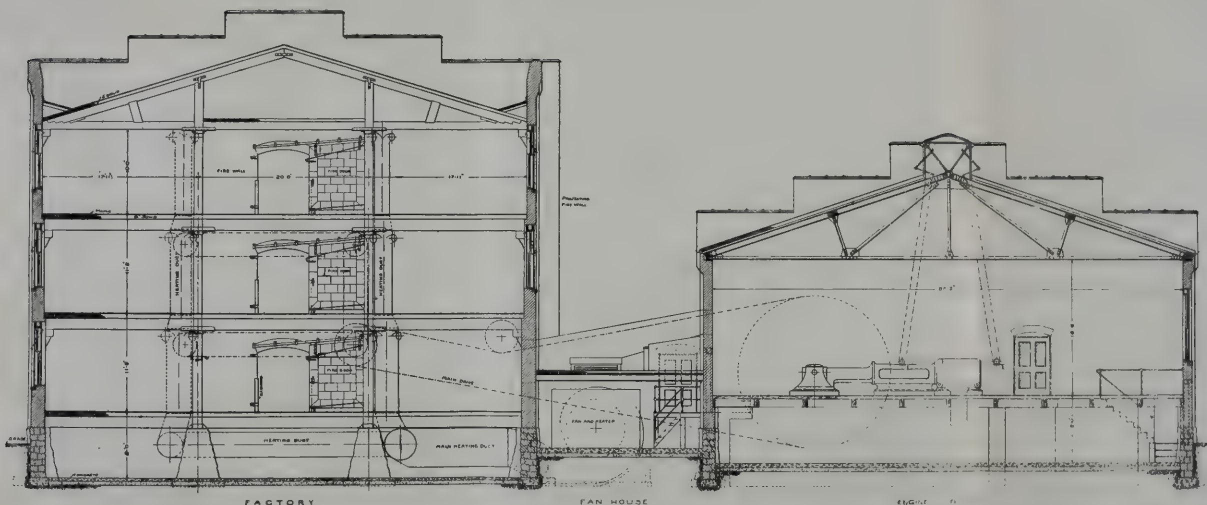

Fig. 12.—Sectional View of Mill Construction Building for Light Woodworking.

as between adjacent rooms which are independently lighted, automatic fire doors of wood, tin-clad, or steel should protect the openings. As a further safe-guard for openings on the exposed sides of buildings, steel fire shutters are sometimes used. In the majority of such cases, these remain open, except in the event of fire, but should be so arranged that they can be closed automatically or by a fire stream. The matter of protecting all vertical openings is an important one, as a means of preventing the loss of life as well as property, and if effectively done a fire can be confined to the floor upon which it starts and its exact location readily determined. Brick walls are the most efficient for enclosing vertical shafts and should be used wherever possible, although wire glass in steel frames serves well where light is a governing factor.

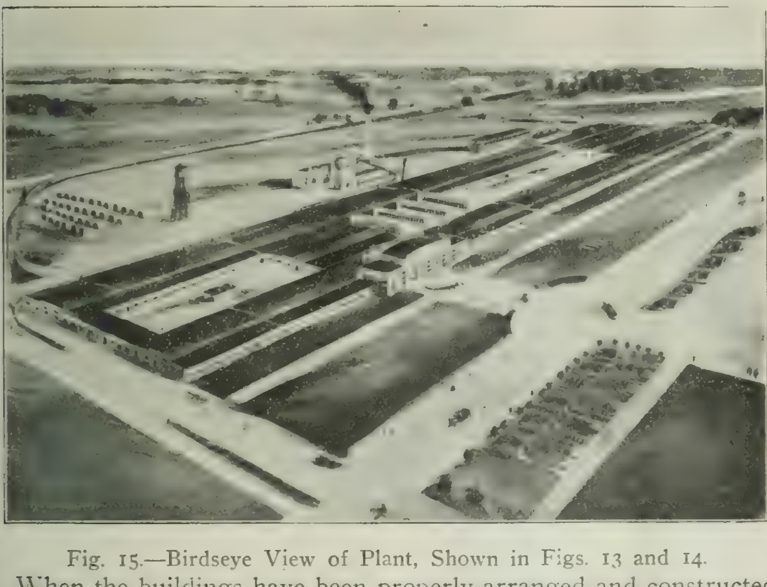

Fig. 15.—Birdseye View of Plant, Shown in Figs. 13 and 14.

When the buildings have been properly arranged and constructed, the fire protection equipment should receive due consideration. The three essential elements involved are the supply, distribution and dispensation of the water. Two independent sources of water supply should be provided and any two of the following will answer the purpose,—a reservoir in connection with a fire pump, a standpipe or gravity tank and a city pressure system. A fire pump should always be installed, even if city water under pressure is available. The reservoir and the standpipe or gravity tank must have capacities governed by the areas of the plant between the fire walls and the stand pipe or tank must have such an elevation as to hold the required volume of water at least twenty feet above the highest portion of any building. The capacity and design of the fire pump are also governed by fixed rules of the underwriters, the capacity depending

upon the size of the plant. The distribution system, consisting of the piping, valves and hydrants, must be tested and made tight at a pressure of 150 lbs. per sq. in., but a pressure of 200 lbs. is more desirable and is to be recommended. Hydrants and hose should be distributed about the premises in such a manner that, when required, lines can be quickly run to any part of the plant. Valves controlling the sprinkler systems should be equipped with indicator posts and placed at such a distance from the building whose equipment they control as to be accessible if that portion of the plant is on fire.

There are but few cases where sprinkler systems are not to be recommended, these being where neither the building nor its contents are of a combustible nature. The sprinklers must be so arranged that every part of the building can be reached by the water and so designed and constructed that they will act promptly and with certainty. This is true of the whole equipment since the successful prevention and extinguishment of fires is dependent upon the reliability of the apparatus. After providing the plant with the best modern fire preventing and controlling equipment, the owner should go one step further and install an automatic alarm system connecting all parts of the plant with the power house and the public fire department.

The protection of towers and chimneys by the use of lightning conductors is not a myth but a reality and should be provided for all such structures. Care must be exercised, however, that the work shall be properly done and well maintained.

Much can be said about the details of construction, but the essential ones are dependent upon the size, location and market conditions for building materials, purposes for which the buildings are to be used, the floor loads imposed and the character of the materials employed in manufacture. Many details, such as the methods of supporting girders at the walls and columns; the design of caps, base plates, pintels and hangers as well as the strength to be provided in the several parts of the buildings, must be left to the skill and experience of the designer, and it does not seem pertinent to the purpose of this paper to enter into a discussion of them. The principal consideration is that all the objects for which the plant is to be built shall be thoroughly understood and carefully considered and all details as well as the general design be made to meet them.

In a strict sense the design of manufacturing plants is more of an engineering problem than an architectual one, and while the appearance may have little or no bearing on the productive efficiency, the architectual treatment should be such that without undue expense the buildings will have a substantial and harmonious effect.

The importance of good natural light in manufacturing plants cannot be overestimated and seldom does any set of conditions arise which prevent its being obtained. This must be supplemented by good artificial light in and about the buildings and as electricity best meets all requirements, and only introduces an element of danger when improperly installed, it should be the only form adopted in modern plants. Generally a system combining arc and incandescent

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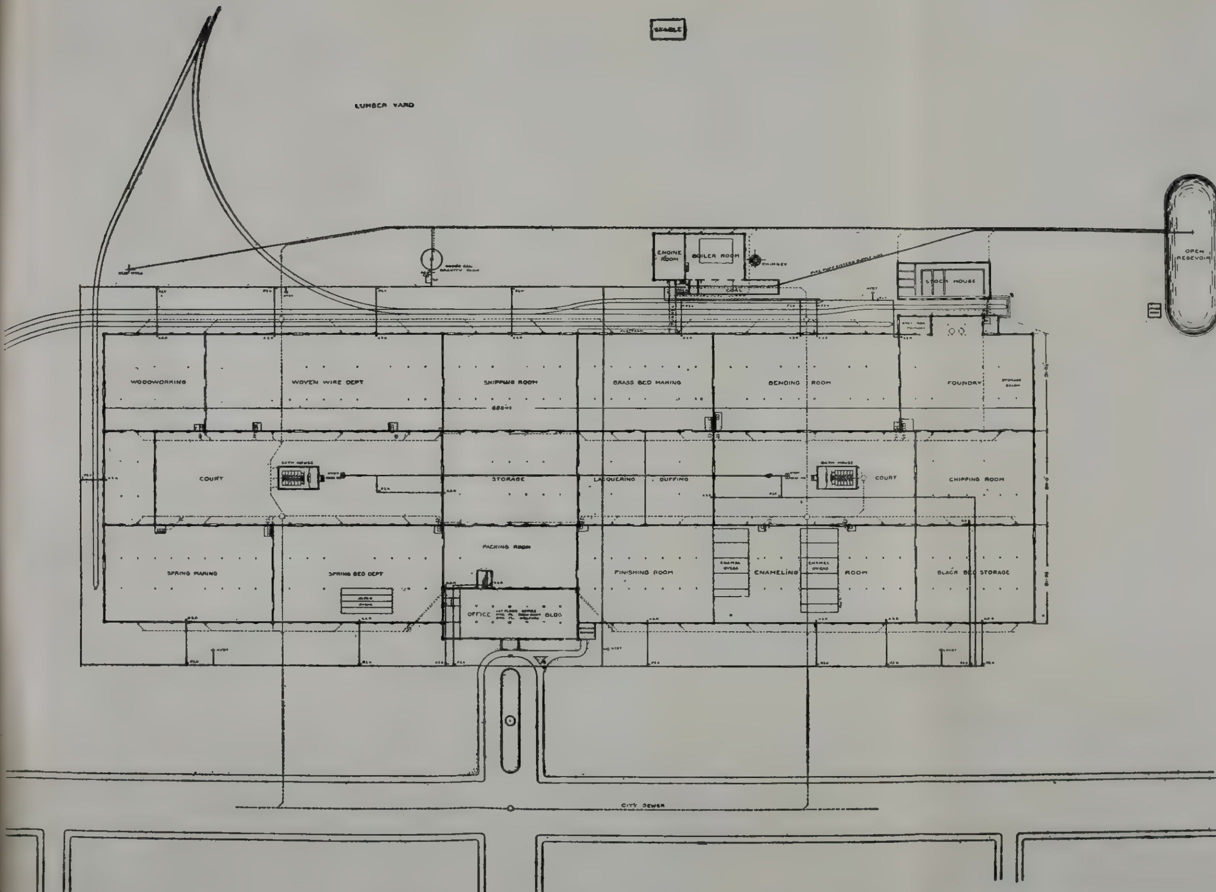

Fig. 13.—General Plan of Plant for Manufacture of Metal Beds—Four Lines of Goods are Produced—Iron and Brass Beds, Woven Wire and Box Springs.

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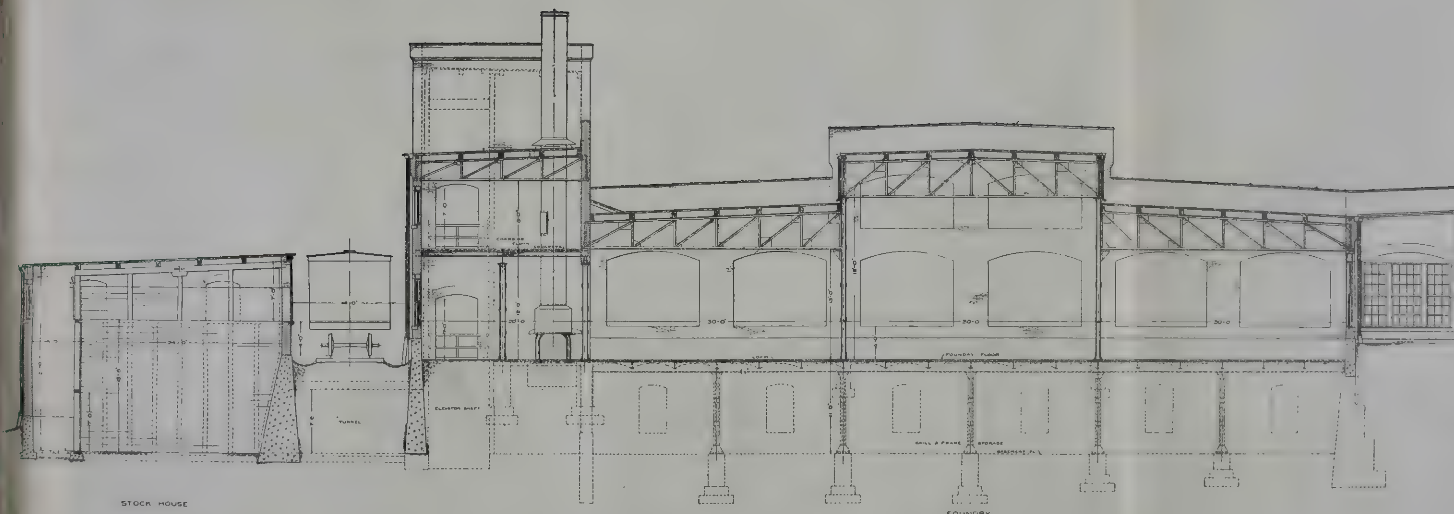

Fig. 14.—Sectional View of Metal Bed Foundry.

lights best serves all needs, the arcs to be used for general illumination and the incandescents for detail lighting. A well lighted plant assists the workmen, facilitates the operations, prevents the accumulation of rubbish, decreases the danger from fires, improves the sanitary conditions and promotes general efficiency.

The size of the windows as determined by their height above the floor will be influenced by the methods of heating and the location of work benches. If heating coils or benches extend along the outer walls the windows will be higher from the floor than would be necessary under other circumstances. If heavy shafting is to be hung from the ceiling, provisions should be made in the girder arrangements for the proper placing of hangers. If motors are to be used without heavy shafting, the floor construction may be designed largely without regard to the methods of transmitting power, for if they are hung from the ceiling their locations will be at irregular intervals and any extra provision for supporting them will necessarily have to be made to meet each requirement. The details of the floor construction and support should be governed not only by the weights which come upon the floors, but the character of the loads. If there are a large number of small machine tools they can be satisfactorily distributed in almost any manner, which the needs of the business indicate, without any especial supporting construction. Where the machines are large or impose severe shocks or vibrations upon the supports, especial provisions should be made for them in the building construction, if they cannot be placed on the ground floors where suitable foundations can be provided. A large amount of such apparatus might influence the general character of the buildings.

The requirements for heating and methods to be adopted should be considered co-incident with the study of the general design and arrangement of the buildings and a decision reached as to the type of equipment best suited to the conditions. If the heating is done by direct radiation, precautionary provisions in the plans may be unnecessary; but if fan systems are used care must be exercised that the distributing ducts will not interfere with any of the other apparatus to be installed. The use of exhaust steam distributed through coils about the several departments forms one of the systems commonly used for factory heating, but it makes no provision for positive ventilation.

If the nature of the work is such that the employees will be crowded together or if the processes are such that noxious gases, dust, lint or other objectionable materials will be produced, it becomes necessary to provide frequent changes of the air. Where the opposite conditions prevail, little ventilation may be necessary. The heating and ventilating may be combined by using an indirect or blower system by which positive ventilation is provided. Where such systems are used and part of the air supply is taken from inside the buildings, it is essential that it be taken from those departments or rooms where the air is free from objectionable elements.

In almost all manufacturing plants there is some use for exhaust steam aside from heating the buildings, such as dry kilns, the heat-

ing of water for various purposes, enameling and japanning ovens, evaporating and distilling. These requirements and their location combined with the method selected for heating the buildings may go far towards determining the type of apparatus in and fixing the location of the power plant. The manner of transmitting power, whether electrical or mechanical, will modify the power plant location and equipment. It should be reasonably near the main plant and so placed that it will not interfere with the manufacturing, shipping or storage operations and as far as practicable not obstruct logical extensions which may be made to the more important buildings.

Adequate and suitable toilet accomodations should be provided throughout every manufacturing plant and if the buildings are of considerable size, it may be well to place closets on all the floors and in locations conveniently accessible without being obtrusive, and so arranged as not to obstruct the manufacturing operations or use valuable space. Lavatories may be placed on each floor, or perhaps still better, assembled in conjunction with a locker-room. Space, convenient of access for employees entering and leaving the plant, may well be set aside for lockers where clothing, lunch baskets, etc., superfluous in the plant, can be safely left and cared for. In many cases this has been found more satisfactory than corresponding conveniences distributed about the plant. To be considered modern, plants should be provided with a lunch-room and some concerns have found it expedient to furnish soup and coffee free, leaving the employees to provide the balance of the meal, while others have served a few well cooked foods practically at cost. The class of help, location of plant, in relation to centers of residence, and the outside facilities for procuring suitable refreshments may best indicate the provisions which should be made and will be appreciated. Self-cleansing drinking fountains, located about the plant, is a sanitary provision amply justified. Usually there need be no real waste incidental to their use; for the overflow can readily be used in the power plant, for flushing or for other purposes where water is required. Baths, especially showers, have been appreciated where installed. The lunch-room or dining-room may be so planned as to be easily convertible into a place for entertainment. Rooms suitable for club purposes and rest-rooms for girls are sometimes desirable adjuncts. Plants of any magnitude and especially those wherein the operations are hazardous should have something in the way of a hospital, with suitable accessories, where emergency cases can be treated. These matters, which in general may be classed under welfare, contribute much to the comfort of the employees and such tendency invariably should and generally does improve the character of the service rendered. While selfish considerations ought not to control in adopting provisions for betterment along these lines, a reasonable investment, properly made, should bring good returns. Of course the nature and extent of the welfare features depend largely upon the character of the work, the degree of skill required and consequently the class of people employed, but everything which tends towards better working conditions raises the standard of labor, improves the

workmanship, increases the efficiency of the workmen and decreases the cost of production.

A small percentage of the total investment can be spent to good advantage in beautifying the grounds and providing attractive surroundings. The effect of this will be felt not only by those employed, but, in connection with a plant suitably designed, will serve as a good advertisement and be considered indicative of good products.

In conclusion it may be said that in all cases compromises in the arrangement and design of the buildings for a site should be avoided as fully as possible. The designer to thoroughly fulfill his obligations, must keep in mind all the conditions imposed by the manufacturing operations; recognize all building ordinances which may pertain to the undertaking; observe all reasonable requirements imposed by the insurance underwriters; give consideration to simplicity and with keen perception bring together all the elements which contribute to the success and integrity of the enterprise. By following these methods he should make every plant fully meet the requirements and therefore result in the highest effiiciency of production.

NOTE—The plants shown in this paper, except Fig. 1, Fig. 6 and Fig. 7, were designed in the office of the author.

DISCUSSION

President Loweth: In the main the speaker agrees with the author in the statement that for manufacturing purposes mill construction is generally desirable, and for storage and warehouse purposes, and possibly for light manufacturing, concrete construction is frequently better suited.

Mr. W. L. Abbott, M.W.S.E.: In a large electric light plant many of the features which Mr. Brill has brought out for a factory will apply equally well. It did not occur to me until after I had begun to consider his paper what analogies there are between a properly constructed electric light plant and a properly constructed factory. I will attempt to make this clear in a blackboard diagram, using the Fisk Street power house of the Commonwealth Edison Company as an illustration.

A diagram of the Fisk Street power house is shown in Fig. 19. The portions enclosed by solid line represent one bay containing two units, each unit consisting of a battery of boilers and a turbo-generator.

At one end of this plan is the train shed, where coal is unloaded from the cars. This corresponds to the receiving room of the factory, where the raw material is delivered. From the train shed the coal is transferred by coal conveyors to the boiler room adjoining, which corresponds to that room in a factory where the first stage of manufacture takes place—the foundry, for example. From the boiler room the steam is conveyed to the adjoining engine room, where the manufacture is completed, and from the engine room the product moves on to the switch-house, where it is distributed to various parts of the city over high-tension transmission lines. This room very naturally suggests the shipping room of a factory.

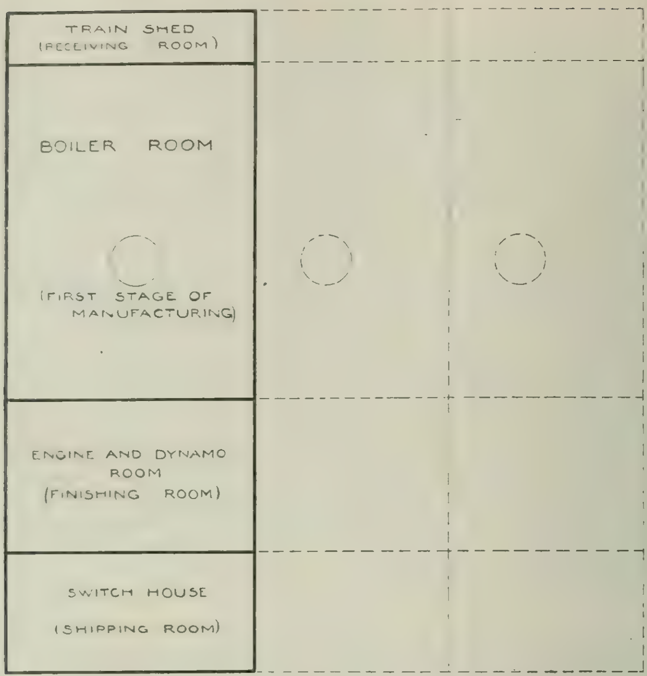

Fig. 16.—Togs in "Discussion," by M. Abbott.

We, therefore, have the raw material delivered at one side of the building and after passing through emerge as a finished product from the other side, as it done in a well appointed factory.

This design for a power house permits the addition of one bay after another, without any interference with the operations which are going on in those portions already completed.

In regard to the toilet and locker facilities which Mr. Brill has referred to, we find it desirable to afford good conveniences for the men,—good bath rooms, wash rooms, locker rooms, etc.;—not in some out of the way place that can be used for nothing else, but in a good, airy portion of the building. We also find it desirable to respect the feelings of the men in the matter of cast, by providing three different sets of locker rooms. For the coal shovelers and ash handlers, —men who are employed for perhaps only a day or two—a place is provided under the boiler room. It is a good, clean, comfortable place, where they can hang their coats, leave their lunches, etc. There is no bath room provided, as they do not need it. For men who are employed regularly about the building, such as janitors, firemen, etc., there are good commodious lockers and toilet rooms provided above the boiler room. For the aristocracy of the place,—the engineers, electricians and office men—there is a meeting room, lavatory rooms, bath rooms, etc., provided above the switch house. Considerable expense is gone to in the matter of glazed tile for inside finish, polished brass, paint, tile floors, etc., not only for the appearance of the room

but for the effect it has upon the men. A man working in a dirty place would be slouching around in his dirty clothes and would not object to having his machinery look dirty, but if everything around him is well kept and bright, it has a beneficial effect upon him and he fixes up accordingly. These things, of course, all cost something, but in a plant costing millions of dollars, the additional expense is a small proportion, and the results obtained from the men have been considered to fully compensate for it.

Mr. C. Kemble Baldwin, M.W.S.E.: I would like to know if the Underwriter Associations require the installing of a sprinkled system, in foundries.

Mr. Brill: They favor it.

President Loweth: Referring to the factory for making metal beds, which the author illustrated and stated was equipped with a sprinkler system; were the sprinklers extended through all parts of the factory? In such rooms where the metal portions only of the beds were stored, sprinklers would seem an unnecessary precaution.

Mr. Brill: Yes, the factory was equipped throughout with sprinklers. Nearly all the beds are wrapped for storage and shipment, with excelsior and paper.

Mr. G. W. Williams: In this connection I might say that the Underwriter Associations do not usually *require* sprinkler installations, but by adopting them a lower rate of insurance can be obtained in any kind of a factory. This lower rate of insurance will pay a large interest on the investment.

President Loweth: In manufacturing plants located outside of the limits served by a city fire department, it is necessary not only to provide adequate fire protection facilities, but in addition, a well trained and disciplined shop fire department, to take care of and use such facilities in the event of a fire.

Mr. Baldwin: I would ask if anyone here has had any experience in lighting factories with the Cooper-Hewett lamp? I understand that in many cases better results are obtained than with the arc lamp,—for instance, at the Oliver Chilled Plow Works.

Mr. Brill: Personally I have not as yet tried them, but have considered them.

President Loweth: In the matter of lighting, the author states that satisfactory natural lighting for most manufacturing purposes cannot be obtained in a building exceeding 60 feet in width. The speaker's experience and observation has been, that with properly arranged window spaces a wider building could be lighted by natural light satisfactorily for most manufacturing work. He has recently designed several shop buildings that have been from 80 to exceeding 100 feet in width, and by making the ceilings high, providing a large proportion of window space in the sides, and using ribbed glass, very satisfactory light was obtained. In foundries and blacksmith shops roof skylights are generally so obscured by dust and smoke that dependence must be had on side lighting.

Mr. Brill: The author thinks that the total cost, or cost per unit of floor space, would have been no greater if the buildings had been

narrower; for to get as good light in a wider building, the story heights must be increased. If the materials being manufactured are rather coarse, the additional width might be necessary, but for many purposes where good light is essential, about 60 feet has come to be recognized as a practical width. In the design of the concrete building shown, this feature was given exceptional attention, and while the story heights are fair, the width was brought down to 52 feet. The width should be fixed by the operations to be carried on; in fact, every feature of the plant should depend on what is to take place in it, if it it to be for a fixed purpose and for a well established company. The first consideration should be story heights and width of buildings, and all details should be made subservient to these. If operations are such that width is desirable, the design should conform to the requirements.

President Loweth: Another reason might be added to those given in the paper, in favor of separating the various processes of manufacture among a group of several buildings, rather than combining them all in one large building, and that is the isolation of noise. The speaker has in mind a large locomotive plant, where the boiler, tank and machine work is all done in one large, undivided building. The noise due to the boiler and tank work appears to be aggravated in this large building, more so than in a smaller one, and conversation is almost impossible at times. He contrasts this with another locomotive plant he is familiar with, where the boiler and tank work is in one shop, and the machine work in another, and believes that the separation results in the latter work being more efficiently done.

Mr. Brill: I regret that I am not at liberty to present a set of plans in preliminary form, of a group of buildings upon which work has been suspended on account of the present financial situation. It is expected that the group of buildings will cover about 28 acres. The different operations are provided for in different buildings,—forging, foundry and wood working, assembling, painting, storage, etc. The proposed scheme is to locate the buildings a sufficient distance apart to provide storage space for the different materials. In the plant which this is to replace, it has been estimated that the expense for handling materials and products amounts to $50,000 per year more than it should in a plant of suitable design, and of ample capacity. The present plant was designed for the same kind of business, but is entirely outgrown.

Mr. P. M. Chamberlain: I would ask Mr. Brill whether for manufacturing purposes he has found anything better than direct current for transmission of energy to any part of the building.

Mr. Brill: There is direct current in none of the plants I have shown you. It is my opinion that alternating current is more suitable, unless there are a number of elevators, cranes, or other loads requiring frequent starting and stopping, when the direct current would be more desirable; or, again, where variation in speed is essential. But for general power purposes, where the plant is started in the morning and is run throughout the day, alternating current is more desirable.

TEST OF A SMALL SUCTION GAS PRODUCER PLANT.

PROF. H. B. MACFARLAND, M.W.S.E.

Presented Feb. 5, 1908.

The object of a test of a suction gas producer is to determine, more than anything else, whether the producer in its form and construction is a good one or not; if a good one, to determine its strong points as well as its weak ones; if not a good one, to determine its defects in order to remedy them. The object of the test may be to determine the capacity of the producer; that is, the number of cubic feet of gas of a proper heating value which it is capable of producing when running under its normal load. The object may be to determine at the same time, the maximum variations which occur in the heating value of the gas during the operation of the producer for any considerable time, notwithstanding the fact, that during that time the load may change suddenly or by degrees from maximum to minimum, and notwithstanding the fact, that the generator will have to receive a certain amount of attention. The attention, of course, being to supply it with coal, to regulate its water supply, to remove any clinker which may be formed and to clean the grate of ashes. In order that the producer may be classified as first class, it must have special attributes,—such as, reliability, capability of being quickly started, of holding fire for a suitable length of time, of being economical in fuel consumption, of not clinkering, of being of a suitable construction and of being easily operated.

REQUIREMENTS OF A PRODUCER.

1. *Reliability.* The producer must be reliable, which in many cases and for many purposes is the chief requisite. Under reliability may be included its ability to produce gas at all times of such a quality and heating value, that a gas engine may be continously operated from such gas, developing its maxium rated power for any length of time. Fortunately, good producers have this property. It should be able to make gas of such a quality that the gas engine may operate for a considerable period of time on light loads. Fortunately, many good producers will fill this requirement, but unfortunately, produces good in all other requirements will not operate on a very light load, or when the engine is running, but not developing power.

2. *Quickly Started.* A producer must be quickly and easily put in operation. This is not a special attribute in all installations, but is necessary where the producer is installed in factories but not necessarily so where the installation is made for a person using his producer in a black-smith shop for instance, or where it is not imperative that the power be on, at a fixed and stated time. A good producer should be making gas of sufficient heating value to start an engine on, in twenty minutes.

3. *Hold Fire.* A producer must be able to hold fire from 12 to 36 hours or longer and started quickly. This attribute may be a subdivision of the first, but not necessarily. For factory work, this is necessary, but the limit may be 14 hours, unless the producer is not cleaned out every Sunday; for intermittent operation, this is imperative. In such a case, one wants a producer that may be left standing for two or three days and can then be started up in a reasonable time with a small stand-by loss of fuel. This ability on the part of a producer is one of its best qualifications, giving it a great advantage over a steam plant and placing it next to the gasoline engine, natural gas or city gas engine as a quick starter.

4. *Economical.* A producer should be economical of fuel. It is not necessary in all installations that the highest economy of fuel be maintained. There must be sufficient economy, however, to warrant the displacement of a gasoline engine by a producer installation so that the increased cost of operation, the interest, depreciation and repairs on the more expensive producer installation over the gasoline installation, with its higher fuel costs, will be covered.

5. *Not Clinker.* A good producer should not clinker. In the practical operation of a producer, there is no one thing that gives more trouble than the formation of clinker in the generator,—either as a clinker that attaches itself to the walls of the generator, or one that forms an arch from wall to wall. All coals contain impurities and in the producer these impurities are fused at high temperatures and form clinkers. The effect of a clinker on the side walls is most disastrous, as it adheres to the walls and when broken off usually brings a portion of the brick lining with it, thus destroying the lining in a short time. The clinker there formed allows the formation of larger cavities for the passage of the entering air and makes the resistance at that point less than at the center of the fuel column. The combustion is consequently near the walls and so further clinker is formed by the high temperatures. Wall clinkers and arch clinkers are a cause of the fire creeping up in the fuel column, thereby decreasing the hot vertical bed of fuel through which the non-combustible carbon dioxide gas is reduced to the valuable combustible carbon monoxide gas. The reduction of the temperature of the fuel column where the oxygen is combined with the carbon of the coal is necessary in order to prevent the formation of clinker. This reduction of temperature is made by the introduction with the entering air of water in the form of steam. At temperatures of about 1700 deg. Fahr., the steam is broken up into its two constituent parts,—hydrogen and oxygen. The hydrogen passes up through the hot fuel bed as a valuable combustible gas, while the oxygen unites with the carbon of the fuel. Up to a proper limit the more steam supplied, the less clinker is formed and the better the heat value of the gas, since there is a smaller per cent of diluent nitrogen in the gas. To have a good gas, however, it is necessary and essential that at all times there is a sufficient depth to the fuel column in order that the previously formed

non-combustible carbon dioxide gas be reduced to the valuable combutsible, carbon monoxide gas.

6. *Suitable Construction.* A good producer must be well constructed. Theoretically the formation of a producer gas by drawing or forcing air containing a certain per cent of moisture through a deep fuel column is a very simple process; practically there are a great many difficulties to be encountered. Too little moisture causes the formation of bad clinkers; too much steam reduces the temperature so much that the gas is bad. One of the most troublesome things to contend with, however, is an air leak. An air leak in the bottom of the generator proper, gives bad results, in that the air passing through the opening contains only a small weight of moisture and consequently reduces the supply of moisture to the producer. At the bottom of the fuel column, the suction should be slight so that a slight leak will give little trouble. Leaks through the brick lining give a great deal of trouble as the air usually passes through the wall at the bottom and out near the top, since the resistence is less by this passage than through the fuel bed. The result is that the good gas already formed may be consumed where the leak occurs. Leaks from the top of the producer itself are liable to be the hard ones to contend with. At this point the suction may be considerable and the gas is usually of such high temperature, that it will burn when oxygen is supplied to it. A leak in any portion of the apparatus after the gas has been cooled below its ignition point is not essentially objectionable because the gas will not be consumed; the added air will, of course, increase the suction at the engine and will require a less quantity of air for a proper mixture at the engine. On account of the great variation of temperatures in certain parts of a producer, there is a liability for a leak to open up at any time. The construction of a producer should then, be such as to insure against leaks in the first place, and the assembling should be such that every part may be easy of access for inspection and of being made air tight. For this reason the application of any insulating material should be made to the inside rather than to the outside of a producer.

Viewed from a commercial side, the construction should be as simple as possible to reduce actual cost of construction and all novel designs which might add to the efficiency of the producer, *thermodynamically considered,* must be rejected from a commercial standpoint in favor of a less expensive construction that may serve the purpose, even though less efficient. Viewed in this light, one will reject devices on a small sized producer that he will install on one of a large size, on account of the varying ratio of cost of the "economical piece of apparatus" to the total cost of construction.

7. *Easily Operated.* A good producer must be easily operated On account of the many variable quantities influencing the operation of a producer, it is impossible to make it automatic in its operation.

Any automatic device which is operated by a variable condition

produced in the generator under variable external conditions is not sure to be reliable and operative day after day and week after week; in fact, it may be inoperative from hour to hour. There are, however, rather uniform conditions upon the whole, so that even a comparatively inexperienced man may soon learn to judge a producer and get good results in operating it. He must discriminate however, in the operation of a producer when the fire is fresh and after the generator has been cleaned, from when the fire has been in operation several days, and when clinkers have been formed on the walls, thereby decreasing the sectional area of the generator at this point and consequently decreasing its capacity.

The things most necessary for the easy operation of a producer are a suitable magazine in which a sufficient amount of coal may be stored to give a fuel supply for several hours, a suitable and proper vaporizer to insure the supply of the maximum amount of steam necessary for the producer, and opportunities to clean the fire properly, whether that be the breaking down of the clinker or the cleaning out the ashes.

Description of Producer.

A producer consists of three necessary and essential parts:—the generator in which the fuel is burned and gasified, the scrubber in which the gas is cleaned of its impurities and at the same time has its temperature and volume reduced, and a vaporizer or economizer which mixes the air supply going to the fuel bed with the proper amount of steam.

The Atkinson Automatic Suction Gas Producer consists of three distinct pieces of apparatus for the generation of producer gas from anthracite coal, coke, or charcoal, suitable for the economic operation of gas engine or for certain industrial processes where high heats are not necessary. Fig 1 is from an elevation outline of a 15 horse power installation of the above mentioned type of producer, in which *A* is the generator, *B* the vaporizer, and *C* the scrubber.

Generator. The generator consists of two cylindrical shells, one telescoped within the other; the outer shell is 27½ in. in external diameter and 36 in. high, it has a closed base or lower end; the inner shell is 22 in. internal diameter and 35½ in. high, a suitable head is bolted to the top of this shell and a lip is cast on its lower end. The shells are of cast iron and each is ½ in. thick. The inner surface of the outer shell and the outer surface of the inner shell have continuous circular suspension rings extending toward each other with properly inclined surfaces so that the inner shell extends only within 9 in. of the bottom of the outer shell.

A flange like projection on the outside of the inner shell, 9 in. from its top keeps the shell in a vertical position and encloses an annular space about the generator. The above mentioned joints are made sufficiently tight by means of a rust joint. In Fig. 2 is

shown an elevation drawing of the generator and scrubber and the connections between the same; the generator is in half section and the vaporizer in complete section. There is a circular cast iron ring resting on the lip at the lower end of the inner shell which carries the brick lining of the generator. The inner diameter of this ring is 8 in. The lower circle of brick is 6 in. high and is specially made so that it slopes back 3 in. in a rise of 6 in., thereby giving a diameter at the base of 14 in., and an area of the fuel column of 1.07

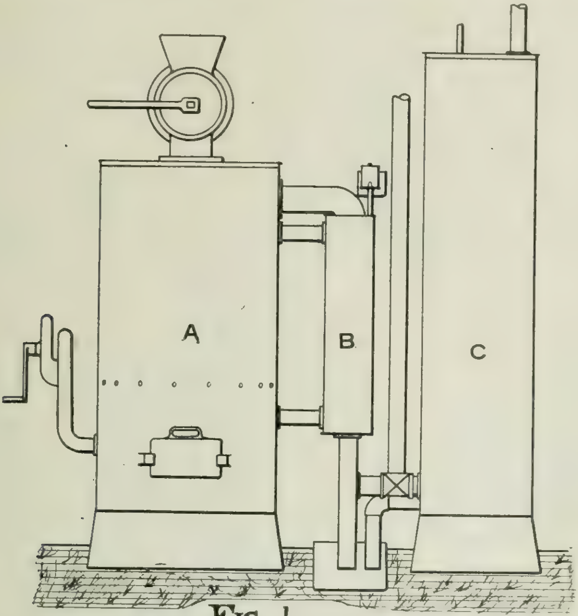

FIG. 1.

sq. ft. On top of this special brick ring there are four courses of circular bricks 3¼ in. thick and 7 in. high, extending to the top of the inner shell. The space between the inner shell and the brick lining of ¾ in. is filled with sand. The bricks are set in a very thin mortar and ground to a joint by rubbing one over the other.

There is no grate in this producer and the fuel column rests on a base of cement 5 in. thick in the bottom of the outer shell and extending to within 3⅞ in. of the supporting ring.

There are two doors to the outer shell, one opposite the other, so that one can get at the base of the fuel column to hook out the ashes or clinker that has formed. The doors are dropped into place and are wedged tight by projecting arms with beveled surfaces to fit corresponding surfaces on the doors. The construction is very simple, the friction of the metals holding the machined surface of the door tightly against the machined surface on the generator, thereby preventing a leak of air to the base of the

generator. A slight tap or blow on the lower edge of the door serves to loosen it.

The head of the outer shell has cast on it a ring 9 in. in diameter and extending downward 12 in., which serves to form a magazine chamber for the storage of fresh fuel within the generator. As fast as the old fuel is consumed the fresh fuel is lowered into the

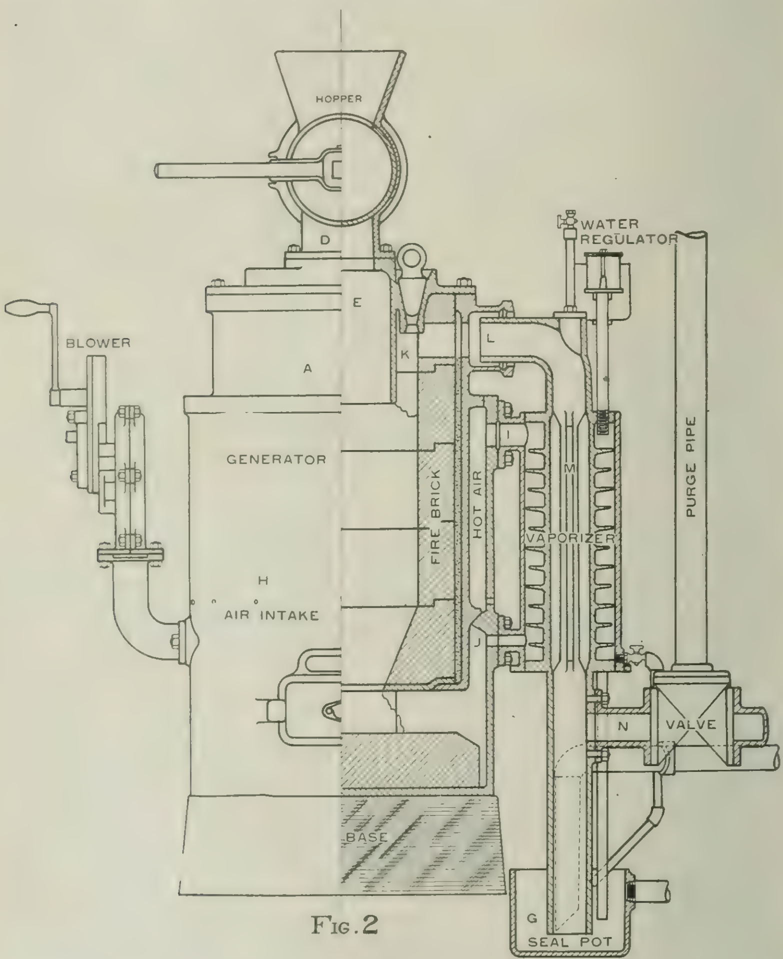

FIG. 2

generator. It is 25 in. from the bottom of this magazine to the bottom of the brick lining; this height is that of the fuel column in which gas is formed. There is about 2 cu. ft. of fuel in the generator furnace. The volume of the magazine is 0.4 cu. ft.; the magazine will hold enough coal to maintain a constant depth

of the fuel bed for one hour at full load or an hour and a half at light load, corresponding to a drop of 5 in. in the fuel column. If the magazine is not filled at intervals of an hour, there is liable to be a variation in the depth of the fuel column.

Bolted to the head of the inner shell is a coal hopper. It consists of a hollow, slightly tapering, cylinder 9 in. in diameter and 10 in. long, fitted into a proper frame. There is an opening 6 in. wide by 7 in. long on the side of the cylinder. When the opening is turned up the cylinder may be filled with coal; by operating a lever the cylinder is given a half revolution and the coal is dumped into the magazine. The construction is such that there is no possible free opening from the air into the generator, consequently no chance for an explosion or the consumption of the gas in the top of the generator.

There are three poke holes in the head of the generator directly over the inner edge of the fire brick lining. They are used when it is necessary to bar down the fire, either morning or at night as the custom may be, and enable one to clean any clinker from the lining of the generator.

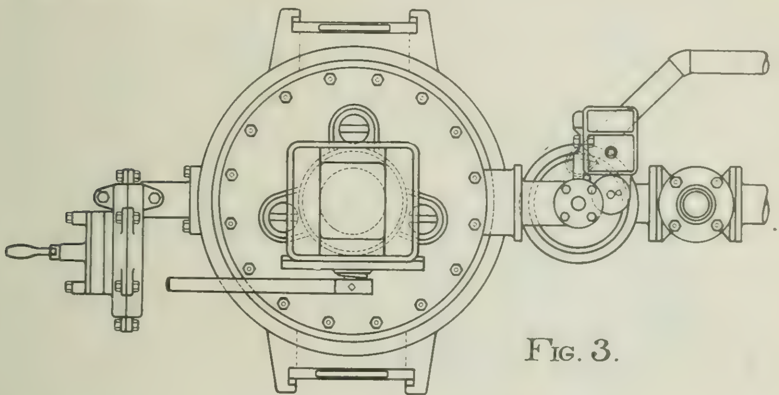

FIG. 3.

In Fig. 3 is a plan view of the generator, vaporizer and scrubber and shows the position of the poke holes in the head of the generator.

There are 12 half inch holes in the outer shell of the generator on the same level and just above the suspension ring, for air admission to the annular chamber. A suitable hand blower is connected to the base of the generator in order to freshen up the fire so as to make suitable gas for starting the gas engine each morning.

Vaporizer. The vaporizer is shown in section in Fig. 2 attached to the side of the generator. It consists of two distinct pieces of cast iron. The shell is 9 in. in external diameter, 23 in. long and ½ in. thick and is connected by cast flanges to the generator. One connection leads to the base of the fuel column below the supporting ring and the other to the top of the annular chamber above the

ring. The inner piece is 3½ in. internal diameter, it extends 24 in. below the bottom of the outer shell of the vaporizer and is connected at its upper end to the gas outlet in the side and near the top of the generator. The lower end of the inner portion extends below the surface of the water in the water seal pot. Just above the seal, connections are made for the gas to pass either to the scrubber or to the purge pipe through a standard three-way cock.

The inner pipe has four interior ribs cast longitudinally extending along that portion which is contained within the outer shell; on its outer surface it has two rings that form the upper and lower heads of the outer shell, and between the two rings there is a series of 22 lugs. Each lug extends half way around the pipe and every other one fits closely to the side of the outer shell. The lugs serve as plates from which the water for the generator drips and is taken up by the air passing from side to side of the vaporizer as it is baffled on its travel through the vaporizer.

There is a water regulator connected to the outer portion of the vaporizer, as shown in Fig. 2. and in Fig. 3. The regulator itself

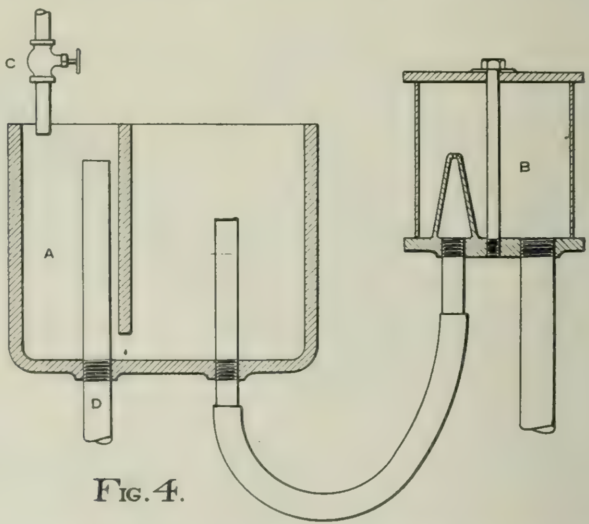

FIG. 4.

is shown more in detail in Fig. 4. It consists of two portions; the cast iron box, *a*, for maintaining a constant head of water, and the glass chamber, *b*, into which water is discharged from the box, *a*, whenever a slight vacuum is in the chamber, *b*. Water is admitted to one portion of the box through the valve *c*, and the quantity not needed runs over the interior partition and is discharged through the pipe, *d*. The chamber, *b*, consists of a glass cylinder 3 in. in diameter and 3 in. high, with air tight ends. There are two connections leading from its lower end,—one to the vaporizer and one to the box, *a*. There is a short thimble in the chamber connected

to the latter connection. Whenever a slight vacuum is produced in the chamber, water rushes through a small hole in the top of the thimble. The water so discharged is proportional to the frequency and the force of the vacuum. A shutter between the generator and upper vaporizer connection is adjusted to regulate the vacuum on the vaporizer.

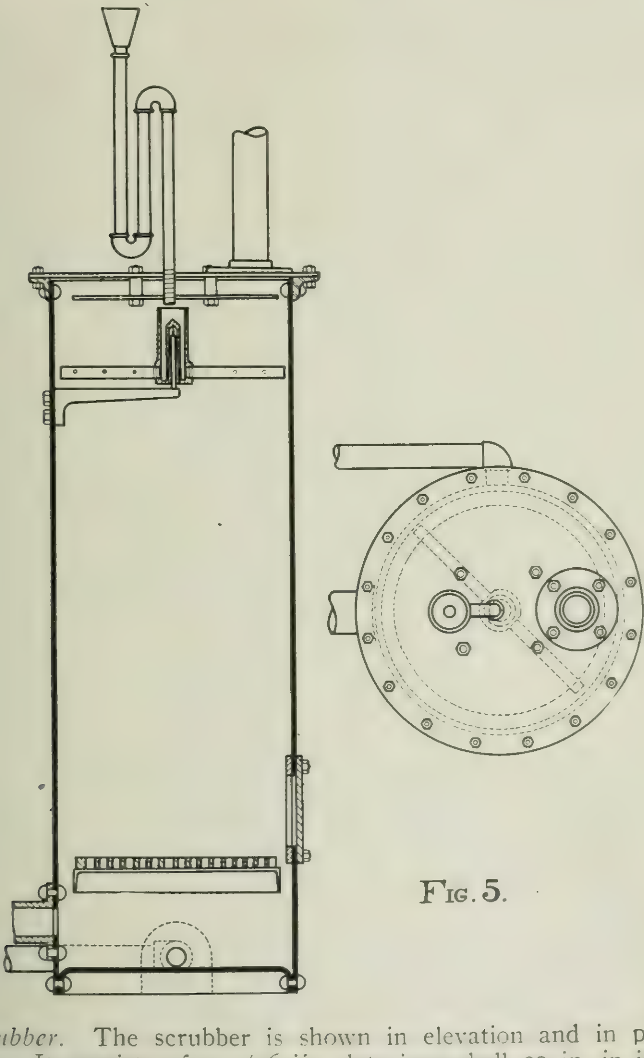

FIG. 5.

Scrubber. The scrubber is shown in elevation and in plan by Fig. 5. It consists of a 3/16 in. plate iron shell 20 in. in internal diameter and 60 in. high. The lower head is riveted in, but the upper head is bolted to an angle-iron which is bent around and

riveted to the top edge of the shell. An angle-iron is bent about the interior of the shell and riveted 10 in. from the bottom of the scrubber. On top of this angle-iron a frame-work of wood is placed to hold up the coke filling of the scrubber.

A door 6 by 10 in. is placed 15½ in. from the bottom of the scrubber to allow of easy removal, when necessary, of the coke which fills the scrubber to within 10 in. of the top.

Water for cooling and cleaning the gas is put into the top of the scrubber through a water seal made of pipe connections; it is discharged through two horizontal arms having small openings in the same. The arms revolve on the principle of "Barker's" Mill and the coke is thereby sprayed uniformly with fine streams of water. An arm, fastened to the inner side of the shell, holds the revolving arms in place. A baffle plate 16 in. in diameter fastened 1 in. from the head of the scrubber, prevents the gas from carrying away any great quantity of water in a body. Gas enters the base of the scrubber through a 2½ in. connection and leaves the top through another of the same size. There is a 1½ in. pipe connection in the bottom of the scrubber, leading to the water seal pot, through which the cooling water is discharged.

Engine. The gas engine is of the horizontal four cycle type with a "hit and miss" governor. It is 8½ in. in diameter of cylinder and 16 in. stroke, running at 230 r.p.m. The engine is designed to operate on producer gas and has a pressure of compression of 180 pounds, with a piston speed of 615 ft. per min. In order to develop 16 horse power at full load it is necessary to have a mean effective pressure of 76 pounds, considering a mechanical efficiency of 80 per cent. The valves are mechanically operated and an auxiliary cam is provided to hold open the exhaust on starting, so that the compression pressure may be reduced. A "make and break" system of ignition is used.

Operation of the Producer.

Fuel. The coal is put into the hopper, *D*, on top of the generator, *A*, shown in Fig. 2. This hopper and the cylinder holds about two buckets of coal. The handle of the cylinder is turned a half revolution and the coal drops into the magazine, *E*, and then sinks gradually into the combustion chamber of the generator as the coal therein is gradually consumed, or sinks more rapidly if the fuel column is lowered by raking out the ashes from the base of the same.

Ashes. The ashes are removed once a day through the ash doors, *F*. The coal is not wholly gasified and a certain per cent runs through the fire when the latter is poked; this unburned coal is considered the same as ash and is removed with the ashes.

Water. The water for the vaporizer is supplied through the regulator as shown in Fig. 4, and has been described. The water for the scrubber is taken in through the goose neck as shown in

Fig. 3, passes through the revolving arms and drips down over the coke in the interior of the scrubber. The water is drained from the bottom of the scrubber through a 1½ in. pipe which leads into the seal-pot, *G*, shown in Fig. 2. From this seal-pot the water overflows to the sewer.

Air. The air enters the generator shell above the suspension ring through the half inch holes, *H*, and leaves through the 2 in. connection, *I*, to enter the top and upper portion of the vaporizer; the air passes from side to side as it is baffled by the plate rings in the vaporizer and leaves the bottom of the same to pass through a 1 in. connection to the base of the generator and to the foot of the fuel column.

Gas. The gas produced leaves the annular chamber, *K*, about the magazine, through the connection, *L*, to pass to the interior of the vaporizer, *M*, thence through the connection, *N*, at the base of the vaporizer through a three way cock to the bottom of the scrubber, *I*, shown in Fig. 3. It then passes up through the wet coke and leaves the top of the scrubber to pass to the engine.

Automatic Gas Making. On the suction stroke of the engine, there is a slight vacuum made in the various pieces of apparatus forming the producer. The effect of this vacuum is to automatically generate gas as it is needed by the engine. Air is drawn in through the holes, *H*, Fig. 2, in the shell of the generator where it is heated from room temperature to more than 300 deg. Fahr. It leaves the shell through the connection, *I*, in which there is an air inlet regulator controlling the vacuum on the water regulator. The heated air enters the top and outer portion of the vaporizer and meets a small stream of water which comes from the water regulator. This water is quickly vaporized and taken up by the heated air. The evaporation of the water reduces the temperature of the resulting mixture. In passing down through the vaporizer the mixture of air and water vapor is heated up because of the heat transmitted from the hot gases in the central portion of the vaporizer to the cooler air on the outer side.

The temperature of the air as it leaves the vaporizer and enters the base of the generator is usually less than that at which it entered the vaporizer, notwithstanding the fact that considerable heat has been transmitted to it in its passage through the vaporizer.

The air and steam in passing from the foot of the fuel column enter into chemical combination with the fuel. The oxygen of the air in combination with the carbon of the coal forms carbon dioxide gas and liberates a quantity of heat. The high heat in the combustion zone decomposes the superheated steam entering with the air into its two component gases,—hydrogen and oxygen: The decomposition of the steam absorbs heat and thereby tends to reduce the temperature of the combustion zone. The hydrogen suffers no further chemical change, but the liberated oxygen unites with the

carbon of the fuel and causes the formation of more carbon dioxide gas.

The carbon dioxide gas formed, passes from the combustion zone of the generator, together with the free hydrogen and the diluent nitrogen, through a considerable depth of heated coal. The temperature is sufficient that a chemical change takes place between the carbon of the fuel and the carbon dioxide,—the latter being reduced to carbon monoxide. The resulting combination of gases is known as producer gas. It contains a small per cent of the volatile gases in the fuel which are distilled from the magazine coal.

The hot producer gas enters the top of the vaporizer, is reduced in temperature as it passes through the same, and is further cooled and scrubbed of particles of dust and ashes as it passes through the wet coke in the scrubber on its way to the engine.

Gas for Starting Up. Gas making is a little different from the automatic process when starting up the engine. The air regulator slide, *I,* is closed and a hand blower, shown to the left in Fig. 2. is operated. Air is blown into the base of the fuel column and as it contains no moisture it serves to increase the temperature of the combustion chamber very quickly. Instead of using a hand blower compressed air may be used more conveniently. The gas first formed is of a very low heating value and is allowed to pass through the purge pipe until it has increased to such a heating value that the engine will start on it. As soon as the engine will start the compressed air is turned off the air regulator opened and the automatic generation of gas begins.

Object of Test.

The object of this test was to determine the efficiency of the installation on full load for a considerable length of time, to determine the full consumption for variable loads, to determine its adaptability to varying loads, and its reliability under all these conditions.

Location.

The plant is installed at the Wheel House of the Weber Wagon Works, 80th St. and Wallace Ave., Chicago, where it has been in operation for more than a year, furnishing power to the line shaft.

Preparation for the Test.

The writer visited the Weber Wagon Works a few days before conducting the test and made such arrangements for such preparation as he deemed advisable in order to conduct the test, and obtain therefrom such sufficient and reliable data as would be valuable to him in making a report on the installation. Means were taken to provide for the measurement of the fuel used, the ashes removed, the temperature of the air at various places, the temperature of the gas generated, the suction in various portions of the

producer, the quantity of the water supplied both to the regulator and to the scrubber, and of the power developed by the engine; as well as to provide for the analysis of the fuel used and the gas made.

Temperature Measurements.

Suitably constructed thermometer cups were placed in various portions of the apparatus to measure temperatures. Carefully calibrated thermometers were placed in these cups which were kept filled with oil at all times.

The temperature of the leaving gas from the generator was made by a *Bristol Electric Pyrometer*, the element of which was placed in the top of the generator through one of the plugs, filling the poke hole of said generator.

Water Measurements.

An "Empire" ⅝ in. water meter was placed in the water line to the scrubber to measure the water used for scrubbing and cooling purposes. A careful calibration of the meter showed that its readings were extremely accurate. The water used by the water regulator was found by difference. The water overflowing from the regulator was caught and returned to the source of supply to the regulator. The amount of make up water supplied at a certain time gave the quantity used.

Pressure Measurements.

The atmospheric pressure was taken by a barometer. The suction in inches of water in the various pieces of apparatus was obtained by inserting ¼ in. pet cocks at the various points and connecting to *U* tubes.

Fuel Measurements.

The fuel as used was taken from a regular fuel bin and weighed on a pair of small accurate scales.

Power Measurements.

The power was absorbed by a form of prony brake. The belt connected to the line shaft was removed and a water cooled pulley was belted to one of the fly-wheels of the engine; a brake strap was applied to this pulley and a wooden strut transmitted the pressure to platform scales.

Gas Analysis.

A small house was erected near the engine in which the analysis of the gas was made; by so doing the gas analysis apparatus was not subjected to changes in temperature or air currents. The gas for analysis was taken through a pet-cock in the gas pipe near the engine.

Arrangement for Conducting Test.

It was first of all arranged to weigh the coal as often as the same was supplied to the hopper and to supply coal at 2½ hour intervals or sooner if necessary. The ashes accumulating during the day were

to be weighed and at the end of the test a sample of the accumulated ashes was to be taken for analysis also a sample of the coal from the bin to the analyzed. The full load test runs were to be of ten hours duration and to continue for two days; the other runs were to be for eight hours. The results were to be given on a test run basis and on a 24 hour day basis.

Description of Test.

Preliminary, May 17th. The producer in question had been operating for a considerable period in furnishing power to the line shaft at the Wheel House, but was shut down at the suggestion of the writer on May 16th. On the afternoon of May 17th, the generator was carefully cleaned of coal and ash and the clinkers removed from the side of the same, as far as possible. The generator, as ready for the test, was in a fairly good condition, and no exception was taken to its condition.

The engine was next overhauled, the valves of the same were removed, and found to be in most excellent shape, although they were re-ground in order to put them in first class condition. No examination was made on the scrubber as it was believed to be in good condition.

A fire was built in the generator on the afternoon of May 17th, and the producer was in suitable condition for operation.

Preliminary Test, May 18th. The producer was blown up until the gas was good and the test was therefore started at 7:00 a. m. with the engine under load. After running for a few minutes, however, the engine stopped, and it was found that the point of ignition was wrong; the engine was firing too late to carry full load. Considerable time was spent in making the adjustment and it was 1:30 p. m. before a second attempt to start was made. There seemed to be a considerable amount of internal friction, which, at the time, was not accounted for, and so the load was thrown off and the engine was run light for 1½ hours; and the producer seemed to meet most satisfactorily this light load test, although it is one of the severe tests which may be put upon a producer plant. During this period of time a sample of the gas was taken and analyzed as follows:

CO_2	7.0%
C_2H_4	...
O_2	0.2
H_2	1.6
CO	22.0
CH_4	0.0
N_2	69.2
Total	100.0%

B.t.u. per cu. ft. 76.6

At 1:30 p. m. a load of 190 pounds was placed on the brake arm and the test was started anew. The engine continued to run for a period of 1½ hours under this load, when it was noted that the main boxes were getting hot and the test was stopped. An examination showed that the load being taken off from the fly wheel, opposite to that from which the load had been taken off for the past few months, necessitated a re-adjustment of the bearings of the crank shaft and a heating of the same No further operation of the engine was made during the day, but the main bearings were taken out and scraped and placed in good condition in order to carry on future tests on succeeding days.

Full Load Test, May 19th. Upon arrival at the plant at 6:30 a. m. the fire was found to be rather low. The compressed air was put on for a few minutes in order to liven up the fuel column; the generator was then poked down from the top through the poke holes, and the ashes were raked out from the bottom of the producer together with some clinker which had formed during the night; the air was then put on and kept on until 7:45 a. m., when the gas was sufficiently good to start the engine.

The test was started at 8:00 a. m.; the fire was cleaned down and the ashes raked from the bottom of the generator, and the hopper was filled with coal. The engine was started under a three-quarter load; at the end of 30 minutes this load was increased, and at the end of a successive 30 minutes, it was further increased and adjustments were made to the air valves so that the engine would operate most economically. Readings were taken of temperature and pressure, and of the water consumption, each half hour during this and successive tests. Gas analyses however, were not made at these short intervals, but were made at intervals of 1½ hours, except in a few special instances. No adjustment was made in the regulation of the air to the engine from 9:00 a. m. until the end of the day, the only attention given to the engine being to keep the bearings suitably oiled. At 10:30 a. m. the coal hopper was turned down and 40½ lbs. of coal were added. At 11:00 a. m. the ashes were raked from the bottom of the fuel column. At this time it was noticed that the engine was missing once in thirty, and the explosions were heavy. At 1:00 p. m. 35¾ pounds of fresh coal were added to the hopper in order to supply the shrinkage of coal in the generator for the preceding interval. At 2:50 p. m., one side of the generator was raked slightly and indications were that the fire was hanging up on that side. At 3.30 p. m., 30¾ pounds of coal were added and it was noted that the temperature of the gases dropped from 905 deg. Fah. to 670 deg. Fah. in two minutes. At 4:30 p. m., 15¾ lbs. of coal were added. No further attention was paid to the generator until the test stopped at 6:00 p. m. The fire was then thoroughly raked from the bottom and 40½ pounds of coal added. At this time 17¼ lbs. of ashes were taken from the producer. During the day, 164¾ lbs. of coal were added. The producer was then banked for the night.

Full Load Test, May 20th, 1907. The air blast was put on at 6:45 a. m., the fire was poked down from the top a few minutes thereafter, and the ashes raked out from the bottom of the producer, together with some clinkers; 27½ lbs. of ashes were taken out at this time which constituted the stand-by accumulation of ashes during the night; 26½ lbs. of coal were added, which constituted the stand-by loss of coal for the night. The blast was put on at 7:00 a. m., and the gas was good for starting at 7:20 a. m. The engine was started up with about 14 horse power, but after it had been running for a period of two or three minutes, it stopped. due to premature ignition. The point of ignition was changed to suit, and a fresh start was made.

Quite a few difficulties were encountered in starting on the morning of this day, and a final investigation showed that the igniter points were in bad shape, and that the points, needed to be replaced. Accordingly, the full losses which occurred from this time until the starting at 9:00 a. m. were not charged up against the producer.

The real test for the day started at 9:00 a. m. with the engine developing about 13 horse power. The producer and engine received very little attention during this day's run; in fact, no adjustments were made. The fire was raked slightly at infrequent intervals and coal was added from time to time in order to keep the supply in the producer up to a standard. At 11:00 a. m., 20½ lbs. of coal were added; at 12:30 p. m., the fire was raked slightly and at 1:00 p. m., 37 lbs. of coal were added. At 2:45 p. m., 22¾ lbs. of coal were added and at 3:30 p. m., the fire was raked. At 4:30 p. m., 33 lbs. of coal were added. At 5:20 p. m., the fire was raked and at 5:35 p. m., 15 lbs. of coal were added. The test was stopped at 7:00 p. m., and 45½ lbs. of coal were added after the fire had been poked down and raked from below, and 20¼ lbs. of ashes removed. During the day's run of ten hours, a total of 175½ pounds of coal were added to the generator.

Three-quarter Load Test, May 21st. The blast was put on at 7:00 a. m., for a period of five minutes; the fire was poked down and raked at 7:15 a. m. The blast was then put on again. The ashes removed, at this time were 13 lbs., which constituted the over-night accumulation; 16 pounds of coal were put into the hopper at this time, which constituted the stand-by losses of coal for the night. The test proper was started at 8:00 a. m. A load of 145 lbs. net was placed on the brake and maintained constant during the entire day. The engine and producer received a minimum amount of attention during the eight hour run, and no adjustments whatever. Occasionally the brake pulley would get a little too hot and necessitate a letting up of the registered load for a very short period of time. At 9:30 a. m., 15¼ lbs. of coal were added. At 10:50 a. m., the generator was raked and poked and 20¼ lbs. of coal added. At 12.00 o'clock the fire was raked slightly and at 2:00 p. m. 18 lbs. of coal were added; at 2:30 p. m., the fire was raked and 32 lbs. of coal were added. Several large clinkers were found

in the producer at this time. At 3:30 p. m., 7¼ lbs. of coal were added. The test was stopped at 4:00 p. m., the fire poked and raked, and the ashes removed; 18¾ lbs. of ashes were removed at this time, and 40¼ lbs. of coal were added in order to fill up the hopper. During the day, 133 pounds of coal were added.

Variable Load Test, May 22. The blast was put on the generator at 7:01 a. m. At 7:09 a. m., the generator was poked and at 7:11 a. m., air was put on again. The fire was raked at 7:12 a. m., and the blast put on at 7:15 a. m. 13½ lbs. of ashes were removed at this time, which was the accumulation of ashes during the night, and at the same time includes the amount of coal that is brought down and wasted when the generator is being poked, it being impossible to prevent fresh coal running down through the generator; 15 lbs. of coal were added to fill up the hopper which constituted the stand-by loss of coal during the night.

The test was started at 8:00 a. m., when the engine was started on a three-quarter load. The temperature in the top of the fuel column was low and the gas of a rather poor quality. After a few minutes, however, the engine carried its load successfully, and was cutting off once in six. The day's test on the engine and producer was a most severe one, running from three-quarters to a full load, to half load, to quarter load, thence to full load, thence to a very light load and then to one-third load. The load was then increased to three-quarters, then to full, then for one half hour the brake was thrown off and the engine ran under no load, but the producer always adjusted itself to the conditions and at no time was there danger of the apparatus stopping due to the variation of the heating value of the gas. After the no load run, a half load run followed, then a full load, then a normally rated load, thence back to full load, then three-quarter load, and finally half load. The average power developed by the engine during the day was 60% of its maximum. At 9:30 a. m. the fire was raked and 26 lbs. of coal added. At 9:50 a. m. the fire was raked, and at 11:10 a. m., 19¼ lbs. of coal were added, and the fire raked. At 12:50 p. m., the fire was raked slightly; at 1:20 p. m., 38¼ lbs. of coal were added, and at 3:05 p. m., the fire was raked and poked down from one side when 24¾ lbs. of coal were added. The test was stopped at 4:30 p. m., when the fire was poked down and raked, and 33 lbs. of ashes were removed, while 29½ lbs. of coal were added to the hopper. During this run, 137¾ lbs. of fuel were used. Adjustments on the engine were made from time to time during the day. At 8:40 a. m., the air valve was adjusted, the engine was practically making no misses. From 9:00 a. m. to 9:30 a. m., the engine was missing half of the time. From 9:30 a. m. to 1:00 p. m., the engine missed 100 times out of 192. From 10:00 a. m. to 10:30 a. m. there was one miss in 28. The air valve or the shutter in the vaporizer was adjusted at 10:02 a. m., the engine lost its speed, making it necessary to remove part of the load for a minute. From 10:30 a. m. to 11:00 a. m., the engine was missing seven in ten

At 10:40 a. m., the air valve was adjusted. From 11:30 a. m. to 12:00 noon, there was one miss in seven. During this period the air valve was adjusted several times. From 12:00 to 12:30 p. m., the engine was missing one in eight. From 12:30 p. m. to 1:00 p. m., three misses in four. From 1:30 p. m. to 2:00 p. m., practically no misses at all. At 1:40 p. m., the air valve was adjusted. At 1:45 p. m., the engine lost speed, so that part of the load seemed to be removed for a very short interval. From 2:20 p. m. to 2:30 p. m., there was one miss in nine. At 2:00 p. m., the air valves was adjusted. From 2:30 p. m. to 3:00 p. m. there were no misses. At 2:50 p. m., the air valve was adjusted and from 3:00 p. m. to 3:30 p. m., there were no misses. At 3:05 p. m., the engine slowed down and the load was removed for a minute. From 3:30 p. m. to 4:00 p. m., there were no misses.

It was evident that the air valves did not stay in place during the day and had to be re-adjusted from time to time on this account. It, however, had to be re-adjusted when the load on the engine was changed by any considerable amount. During this day's run, 137¾ lbs. of coal were used.

On the next morning the producer was started up as is customary and 13¾ lbs. of ashes were removed, which was the accumulation of ashes over night, and 19¼ lbs. of coal were added, which constituted the stand-by loss of coal during the night. The fire was all pulled out and the interior of the generator was examined. A considerable amount of clinker was found on the side of the generator, and it was especially bad under that portion where one poke hole was missing. It is to be noted that there were only three poke holes in the top of the producer.

Description of Record.

The complete record of the daily tests is given at the end of this paper, together with the deductions made therefrom. The items will be taken up and discussed separately.

Item No. 1 is the time interval when readings were made.

Item No. 2 shows the number of pounds of fuel added to the hopper.

Item No. 3 shows the number of pounds of ashes removed from the generator as well as the number of pounds of coal for stand-by losses for the night following the date of test.

Item No. 4 shows the pressure of the barometer in inches of mercury.

Item No. 5 shows the suction, in inches of water, of the gas, taken between the scrubber and the engine.

Item No. 6 shows the suction, in inches of water, of the gas passing from the vaporizer to the scrubber.

Item No. 7 shows the suction, in inches of water, of the air at the fuel column, due to the resistance it encountered in passing through the vaporizer, and air regulator.

Item No. 8 shows the temperature of the air on the outside of the generator as it entered the jacket of the same.

Item No. 9 shows the temperature of the air just as it was passing from the upper portion of the jacket of the generator to the vaporizer. The difference between items No. 8 and 9 shows the rise in temperature of the air as it passed through the jacket of the generator.

Item No. 10 shows the temperature of the air and moisture added thereto, in the vaporizer at the fuel column. The difference between items No. 9 and 10 indicates the quantity of heat added to the air and water, and taken in part from the vaporizer and in part from the base of the fuel column.

Item No. 11 is the room temperature of the air as it entered the suction pipe leading to the engine.

Item No. 12 is the temperature of the gas in the top of the generator as it passed to the vaporizer, indicated by a Bristol Electric Pyrometer inserted therein.

Item No. 13 shows the temperature of the gas after it had passed through the vaporizer and was about to enter the scrubber. The difference between items No. 12 and 13 indicates the change in temperature of the gases, or the cooling effects of the vaporizer.

Item No. 14 shows the temperature of the gas at the top of the scrubber which is practically the temperature as it enters the mixing valve of the engine.

Item No. 15 shows the temperature of the city water going to the scrubber.

Item No. 16 shows the temperature of the water leaving the scrubber. The difference between items No. 15 and 16 is the increase in temperature of the water as it passes through the scrubber.

Item No. 17 is the reading of the dial of the water meter, indicating the number of cubic feet of water consumed at that instant.

Item No. 18 shows the actual reading of a continuous revolution counter placed on the air intake valve of the engine.

Item No. 19 shows the number of pounds of water going to the scrubber. This was made from item No. 17, except for a portion of the test when the meter was not registering and then the water was weighed for a portion of the time, in order to determine the average rate of flow for the given period of time.

Item No. 20 shows the number of pounds of water which passed into the vaporizer and thence to the base of the fuel column. This item was made up by taking the difference of water supplied to the regulator and that leaving the same.

Item No. 21 shows the total number of revolutions of the engine for the previous interval of time. It is twice the difference of successive readings in item No. 18.

Item No. 22 shows the average number of revolutions for a period of thirty minutes, and is deduced from item No. 21.

Item No. 23 shows the average revolutions of the engine for one minute as deduced by reading the revolution counter one minute before item No. 18 was taken.

Item No. 24 shows the net load on the brake arm of the pulley.

Item No. 25 shows the horse power developed at the brake determined for the previous half hour period, as determined by the results obtained in items Nos. 22 and 24.

Item No. 26 shows the same horse power as standardized. This is an arbitrary item and is based on the probable power which the engine would produce if the air and gas were each supplied at a temperature of 62 deg. instead of the temperature indicated in items No. 11 and 14. It also includes the power that would be developed had the barometer stood at 30 inches of mercury instead of that indicated in item No. 4.

Items Nos. 27 to 33 inclusive, show the constituent parts of the producer gas as shown by analysis. The analysis of the gas was made with a Morehead apparatus.

Item No. 34 shows the high heating value of the gas standardized 62 deg. F., 30 inches mercury, calculated from tables in the appendix.

Item No. 35 shows the low heating value of the gas at the above mentioned standard. At the end of the sheet a few general remarks are made.

Analysis of Fuel.

At the conclusion of the test a sample of coal from the bin was taken according to approved methods and was analyzed with the following results:

Approximate Analysis of Coal.

Moisture	3.08%
Volatile Matter	7.41
Ash	11.07
Fixed Carbon	78.44
Total	100.00%

Heating Value, 12,546 B.t.u per pound.

The heating value was determined by the Mahler-Bomb Calorimeter.

Ashes.

At the end of the two days of the full load test, the total ash removed from the generator during this time was sampled and its average heating value as determined, was 7057 B.t.u. per pound. The ash accumulation during the two following days was sampled and its average heating value was 7119 B.t.u.

Summary of Results.

The following is a summary of the results obtained during this test and as shown by the tables appended, and as deduced from the results shown therein.

Date, 1907.	May 19th.	May 20th.	May 21st.	May 22d
Length of test, hours	10	10	8	8
Nature of test, load	Full	Full	¾	Variable
Coal used, pounds	164.75	173.5	133.0	137.75
Ashes removed, pounds	17.25	21.25	18.75	33.0
Coal, pounds, stand-by loss	26.5	16.0	15.0	19.25
Ashes, pounds, stand-by	27.5	13.0	13.5	13.75
Total coal, full day, lbs.	191.25	189.5	148.0	157.0
Total ashes, full day, lbs.	44.75	34.25	42.25	46.75
Work done, H. P. hours	160.6	162.0	102.7	83.2
Average H. P. developed	16.1	16.2	12.9	10.4
Total rev. of engine	134,414	135,192	110,938	110,374
Average r. p. m. of engine	224.2	225.3	231.1	229.9
Water to vaporizer, lbs.	35.38	35.08	24.52	21.78
Water to scrubber, lbs.	3,135	3,483	3,534	9,178
Water to scrubber, gallons	376.	418.	424.	1,101.
Average B.t.u. of gas at 62 degrees 30 in.	111.0	113.3	112.0	109.9
B.t.u. in coal, for test	2,066,950	2,176,730	1,668,620	1,728,210
B.t.u. in ashes, for test	121,730	149,960	133,480	234,930
B.t.u. in coal, full day	2,399,420	2,377,470	1,856,810	1,969,720
B.t.u. in ashes, full day	315,800	241,700	300,700	332,815
B.t.u. per B.H.P.-hr. test run	12,870	13,440	16,250	20,770
B.t.u. per B.H.P.-hr. full day	14,940	14,600	18,080	23,680
Lbs. coal per B.H.P.-hr. test run	1.02	1.07	1.29	1.66
Lbs. coal per B.H.P.-hr. full day	1.19	1.17	1.43	1.88
Lbs. water per H.P Vaporizer	0.22	0.22	0.24	0.26
Lbs. water per H.P. Scrubber	19.5	21.5	34.3	110.3
Lbs. coal per sq. ft. area per hour	15.4	16.2	15.6	16.1
Grate eff. per cent, full day	86.8	89.8	83.8	83.1
Efficiency of installation, per cent, test run	20.4	20.4	15.7	12.2
Efficiency of installation, per cent, full day	17.0	17.3	14.0	10.7

Rating of the Engine.

The horse power rating of this engine must be determined by the maximum horse power, standardized, that the engine is capable of developing for a considerable period of time multiplied by a certain factor which is adopted in practice. Engineers have used the factor of 85% in estimating the rated capacity of a gas engine. This engine developed for two days an average of 16.9 horse power, corrected to standard conditions, at an average of about 225 r.p.m.

Upon the above basis, then the rated horse power of this engine at 225 r.p.m., and with a factor rating of 85%, will be 14½ horse power.

May 19. FULL LOAD RUN, 10 hrs.

Time.	Fuel used, lbs.	Ashes removed, lbs.	Barometer, "Hg	Suction, ins. water: Gas at engine	Suction, ins. water: Gas to scrubber	Suction, ins. water: Air at fuel column	Temperature—Deg F. Air: To jacket	Air: To vaporizer	Air: At fuel column	Air: To engine	Gas: To vaporizer	Gas: To scrubber	Gas: To engine	Water: To scrubber	Water: From scrubber	Readings	Readings: Revolution counter
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
8:00			2944	425	430	100		168	176	74	260	180	60	52	67		28333
8:30			2944	400	420	200	89	176	184	76	275	186	60	56	64		31758
9:00			2943	345	4.10	160	93	180	194	78	375	208	63	58	84		35160
9:30			2942	395	425	165	102	196	194	80	485	284	65	64	96		38529
10:00			2942	400	420	1.65	106	218	213	84	675	272	70	64	107		41876
10.30	40.50		2941	410	425	180	106	241	227	85	600	254	70	64	99		45206
11:00			2941	395	410	165	107	267	23.9	83	700	280	6[illegible]	58	93		48552
11:30			2941	410	4.15	170	110	287	253	86	705	302	67	58	92		51892
12:00		Stand-by loss, Cool, Lbs., 2650. Ashes, ,, ,, 2750	2940	425	4.30	190	114	310	271	85	805	316	[illegible]8	58	90		55251
12:30			2939	425	4.40	140	116	335	282	86	870	342	68	57	92		58631
1:00	35.75		2938	410	4.20	100	118	356	291	88	700	318	6[illegible]	59	98		61990
1:30			2937	410	410	095	120	370	298	87	820	342	69	60	97		65377
2:00			2937	4.10	410	090	127	380	309	87	840	360	69	57	99		68758
2:30			2936	410	4.10	0.90	124	396	321	88	880	376	69	57	98		72141
3:00			29.36	460	4.50	085	122	410	329	89	900	380	69	57	99		75529
3:30	30 25		2935	420	415	1.10	123	410	332	88	715	360	69	57	106		78847
4:00			2935	425	4.00	100	126	425	333	86	900	372	68	57	104		82235
4:30	15.75		2935	410	410	100	126	430	340	85	940	375	66	54	108		85562
5:00			2936	375	395	090	124	430	337	82	900	430	67	58	106		88901
5:30			2938	390	400	0.75	130	435	342	82	950	435	64	58	108		92226
6:00	42 50	1725	2940	390	380	080	126	437	345	82	980	437	64	57	110		95540
Aver			2939	409	415	135	120	327	277	84	728	326	67	58	96		
Total	164.75	1725															

Time.	Water lbs.: To scrubber	Water lbs.: To vaporizer	Revolutions: Total of engine.	Revolutions: Average for 30 minutes.	Revolutions: For 1 min	Net load on brake 23⅜ arm	H. power per hour: Developed	H. power per hour: Standardized	Gas analysis—per cent: CO_2	C_2H_4	O_2	CO	H_2	CH_4	N_2	Heating value 62° F. 30" Hg: High	Heating value: Low	Remarks
1	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	
8:00						155			6 0	0.0	08	196	87	12	637	1042	985	Test started at 8:00.
8:30	74	1.23	6850	228.3	228	170	13.4	138										
9:00	74	119	6804	226 8	228	185	146	151										
9:30	74	1.06	6738	224.6	224	190	15.7	163	32	01	1.1	244	10.5	0.6	60.1	121.2	115.1	
10:00	192	147	6694	223.1	[illegible]22	190	163	171										
10.30	192	136	6660	222.0	222	1[illegible]0	16.2	17.1										
11:00	192	1.56	6692	223.1	224	190	16.3	17.1	32	02	08	260	6.1	22	615	1299	1243	Raked fuel column.
11:30	192	1.45	6680	2227	220	190	16.2	17.0										
12:00	183	1.50	6718	223.9	224	190	163	171										
12:30	183	211	6760	225.3	224	190	164	172	40	0.0	14	26.2	7.7	0.6	601	116.2	111.7	
1:00	183	220	6718	223.9	228	190	163	172										
1:30	183	2.16	6774	225 8	228	190	165	174										
2:00	174	1.65	6762	225.4	220	190	164	173	40	0.0	1.4	264	50	0.0	63.2	1020	994	
2:30	165	1.65	6766	225.5	224	190	165	174										
3:00	166	2.31	6776	225.9	226	190	165	17.4										Raked one side of fire.
3:30	165	228	6636	224.5	224	190	164	17.3	52	0.0	10	25.2	38	0.0	64.8	[illegible].2	922	
4:00	165	1.91	6776	225.9	222	190	16.5	17.4										
4:30	165	220	6654	221 8	222	190	16.2	17.0										
5:00	138	1.98	6678	[illegible]22.6	222	190	16.2	170	[illegible]6	0.0	1.6	274	7.3	0.0	61.1	112.7	109.0	
5:30	138	202	6650	221.7	2[illegible]0	190	162	169										
6:00	138	209	6628	220.9	224	190	161	16.8										Test stopped at 6:00.
Aver	157	1.77	6721	22[illegible].2	224	187	16.1	169	40	00	11	250	70	0.7	61.2	1110	106.7	
Total	3135	35.38	134414															

FIG. 6.

May 20, FULL LOAD RUN, 10 Hrs.

Time	Fuel used, lbs.	Ashes removed, lbs.	Barometer, "Hg.	Suction ins water: Gas at engine	Suction ins water: Gas to scrubber	Suction ins water: Air at fuel column	Temperature.—Deg. F. Air: To jacket	Air: To vaporizer	Air: At fuel column	Air: To engine	Gas: To vaporizer	Gas: To scrubber	Gas: To engine	Water: To scrubber	Water: From scrubber	Readings.	Readings: Revolution counter	Water lbs.: To scrubber	Water lbs.: To vaporizer	Revolutions: Total of engine	Revolutions: Average for 30 minutes	Revolutions: For 1 min.	Net load on brake, 23⅜" arm	H power per hour: Developed	H power per hour: Standardized	Gas analysis.—Per cent: CO_2	C_2H_4	O_2	CO	H_2	CH_4	N_2	Heating value 62°F. 30" Hg.: High	Heating value: Low	Remarks.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	
9:00			2965		275	0.80	93	168	276	75	310	176	82	54	66		097665					234	145			4.6	0.1	1.1	22.0	9 9	1 2	611	1159	1096	Test started at 9.00.
9:30			29.66		275	060	92	234	302	81	482	224	66	63	76		101101	222	1.87	6872	229.1	206	180	12.7	13.1										
10.00			2968		325	0.70	91	238	302	84	684	266	69	62	84		104090	216	1.54	5978	199.3	222	190	13.7	14.2										
10.30			29.69	3.70	3.20	070	94	261	300	86	687	292	69	61	91		107624	[illegible]	187	7068	235.6	220	190	17.2	179	3.2	0.0	0.8	27.2	6.7	1.1	61.0	1213	1168	
11:00	2025		2969	3.65	300	080	100	303	307	86	720	308	71	63	92		111241	189	1.52	7234	241 1	220	190	176	18.3										
11 30			29 69	[illegible]	290	0.70	92	315	311	88	754	318	70	63	93		114516	198	1.54	6550	218.3	228	190	15.9	16 6										
1200		Stand-by loss, Coal, Lbs, 16 ... Ashes, ... 13.	29.70	3.20	3.00	080	96	331	319	88	767	329	72	64	94		118092	210	1,25	7052	235.1	220	190	17.1	179	2.8	0.0	0.8	28.0	5.0	0 6	62.8	1132	110.0	
12 30			29 70	3.55	3.10	060	98	341	325	80	830	328	72	65	89		121286	186	1 67	6488	216.3	228	190	15.8	16.4										Fire raked.
1'00	3700		2970	3 20	3.00	085	115	357	337	94	820	387	69	60	97		124682	189	1.58	6792	226.4	226	190	16.5	17.3										
1.30			29 70	3.15	3.00	075	102	376	340	91	812	332	69	61	98		127991	177	191	6618	220.6	220	190	16.1	16.8	22	0.2	0.4	[illegible]	8 5	0.6	60.1	1278	1227	
2'00			29 70	3.15	3.05	0.60	98	383	342	88	850	342	71	63	100		131474	183	1.50	6966	232.2	224	190	16.9	17.7										
2:30	2275		29.70	3.00	300	070	94	390	345	92	960	362	70	62	99		134988	174	1.69	7028	2343	224	190	17 1	179										
3:00			29.70	[illegible]	290	0.60	102	399	349	88	965	356	70	62	98		138268	183	1,87	6560	218.7	228	190	16 0	16.7	2.4	0.0	0.4	[illegible]	6.2	1.2	61.0	1258	121.4	
3:30			29 70	3.15	285	0.70	110	404	352	[illegible]	970	364	72	63	105		141779	177	1.17	[illegible]	234.1	226	190	17 1	179										Fire raked.
4:00			29 70	330	315	080	110	415	360	81	1000	373	71	63	107		[illegible]	159	1.94	6854	228.5	228	190	167	17.5										
4'30	3300		[illegible]	330	3.20	0.80	116	[illegible]	367	92	770	372	72	62	112		148282	165	3.15	6152	205.1	206	190	15.0	15.7	3.6	0.0	0.4	28.0	5.0	0.6	62.4	113.2	110.0	
5 00			29 70	340	310	085	116	430	368	87	1020	386	70	[illegible]	108		[illegible]	165	1 54	7908	263.6	218	190	19 2	20.0										Fire raked
5'30	1500		2968	3 30	330	070	117	490	371	83	1000	384	70	57	111		155846	153	152	6020	200.7	222	190	14 6	15.2										
6'00			2967	3.40	340	0.70	117	440	372	77	1070	394	64	54	107		158464	153	2.40	6436	214 5	226	190	15 6	16 1	3.6	0.0	0 4	26.0	6.4	0 6	63 0	111.4	1075	
6:30			2966	350	310	065	116	445	375	75	1075	398	64	56	126		161911	96	205	6894	2298	226	190	16.8	172										
7'00	4550	21.25	2965	350	320	075	113	440	377	71	1060	406	63	57	121		165261	78	150	6700	223.3	228	190	163	167										Test stopped at 7.00.
Aver			29.69	330	305	072	109	359	338	85	839	335	70	60	99			174	175	6760	225.3		187	162	169	3.2	00	06	269	6.8	08	617	1176	1133	
Total.	17350	2125																3483	3508	135192															

FIG. 7.

May 21, THREE-QUARTER LOAD RUN, 8 Hrs.

Time	Fuel used, lbs.	Ashes removed, lbs.	Barometer, Hg.	Suction, ins water: Gas at engine	Suction: Gas to scrubber	Suction: Air at fuel column	Temperature.—Deg F. Air: To jacket	Air: To vaporizer	Air: At fuel column	Air: To engine	Gas: To vaporizer	Gas: To scrubber	Gas: To engine	Water: To scrubber	Water: From scrubber	Readings: Water meter, to scrubber, cu ft	Readings: Revolution counter	Water, lbs.: To scrubber	Water, lbs.: To vaporizer	Revolutions: Total of engine	Revolutions: Average for 30 minutes	Revolutions: For 1 min.	Net load on brake, 23¾ arm	H. power per hour: Developed	H. power per hour: Standardized	Gas analysis—per cent: CO_2	C_2H_4	O_2	CO	H_2	CH_4	N_2	Heating value 62°F 30 Hg.: High	Low	Remarks.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	
8:00			2977	3.75	325	100	66	205	212	59	[illegible]60	190	53	51	60		166208						145			30	00	08	262	23	0.5	672	976	959	Test started at 8:00
8:30			2975	4.25	275	076	76	231	230	66	330	226	60	67	80		169804	141	1.43	7192	239.7	242	146	13.3	13.4										
9:00			2974	3.50	3.25	1.25	85	242	236	66	530	254	50	58	84		173374	141	1.64	7140	238.0	[illegible]38	145	13.2	13.2										
9:30	15.25		2974	3.75	3.00	1.25	82	262	246	72	530	264	63	54	84		176892	166	1.52	7036	234.5	236	145	13.0	13.2	2.8	0.0	1.4	26.8	7.6	0.6	60.8	1179	1134	
10.00		Stand-by losses, Coal, Lbs, 15.0; Ashes, 13.5	2974	3.75	2.50	0.80	86	282	260	75	640	272	66	69	84		180379	183	1.76	6974	232.5	234	145	12.9	13.2										
10:30			29.74	3.50	2.50	0.80	82	300	270	76	680	286	66	58	82		183802	186	1.76	6846	228.2	218	145	12.7	13.0										
11:00	20.25		2972	2.80	2.50	1.00	96	320	286	72	600	278	68	69	84		187206	193	1.63	6808	226.9	234	146	12.6	12.9	4.0	0.0	0.8	26.2	9.9	1.2	59.6	124.3	118.4	Fire raked and poked.
11:30			2971	3.00	[illegible]50	100	94	338	290	80	690	285	70	62	86		190622	255	1.28	6832	227.7	228	145	12.7	13.1										
12:00			2970	2.75	2.25	1.00	96	342	308	84	710	305	66	58	76		194004	266	1.34	6764	225.5	230	145	12.5	12.9										Fire raked.
12:30			2970	3.00	2.25	100	98	364	317	79	790	310	68	55	71		197385	192	1.41	6762	225.4	224	145	12.5	12.9	3.2	0.0	0.8	27.0	8.2	0.6	60.2	120.4	115.6	
1:00			2969	3.25	2.50	100	96	374	322	76	840	322	66	57	72	2821.5	200812	258	1.21	6854	228.6	234	145	12.7	13.1										
1:30			2968	3.50	2.75	100	98	384	326	84	910	342	78	57	86	2826.6	204308	262	1.41	6992	233.1	232	145	13.0	13.5										
2:00	18.00		2967	3.75	3.00	1.50	96	394	334	84	970	364	68	56	86	2829.9	207776	267	1.45	6936	231.2	236	145	12.9	13.4	3.8	0.0	0.6	26.6	7.7	0.6	60.7	117.5	113.0	
2:30	32.00		2966	3.25	3.25	1.50	112	406	340	90	1080	390	72	62	89	2834.1	211240	260	1.69	6928	230.9	236	145	12.4	13.6										Fire raked.
3:00			2965	3.50	3.25	2.20	116	416	344	92	930	372	72	62	90	2838.4	214723	267	1.67	6966	232.2	234	145	12.9	13.5	3.6	0.0	0.8	26.0	9.2	0.6	59.8	120.5	115.2	
3:30	7.25		2965	3.60	3.25	2.20	116	420	348	90	1020	392	73	62	93	2842.6	218207	260	1.71	6968	232.3	230	145	12.9	13.5										
4:00	40.25	18.75	2965	3.50	3.25	2.25	116	425	352	88	1070	406	71	62	93	2846.9	221677	267	1.67	6940	231.3	230	146	12.9	13.5										Test stopped at 4:00.
Aver			2971	3.45	2.80	1.26	95	336	295	78	740	309	66	58	82			221	1.53	6934	231.1	232	145	12.9	13.4	3.4	0.0	0.9	26.3	7.4	0.7	61.3	116.5	112.0	
Total	133.0	18.75																3534	24.52	110938															

FIG. 8.

May 22. VARIABLE LOAD RUN, 8 Hrs

Time	Fuel used, Lbs	Ashes removed, Lbs.	Barometer, "Hg.	Suction ins water: Gas at engine	Suction ins water: Gas to scrubber	Suction ins water: Air at fuel column	Temprature – deg F. Air: To jacket	Air: To vaporizer	Air: At fuel column	Air: To engine	Gas: To vaporizer	Gas: To scrubber	Gas: To engine	Water: To scrubber	Water: From scrubber	Readings: Water meter to scrubber, cu. ft.	Readings: Revolution counter	Water lbs.: To scrubber	Water lbs.: To vaporizer	Revolutions: Total of engine	Revolutions: Average for 30 minutes	Revolutions: For 1 min.	Net load on brake 23⅛ arm	H. Power per hour: Developed	H. Power per hour: Standardized	Gas analysis – per cent: CO_2	C_2H_4	O_2	CO	H_2	CH_4	N_2	Heating value 62° F. 30 Hg: High	Heating value: Low	Remarks.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	
8:00				375	350	200	68	165	155	68		224	56	54	66	2853.2	222891					230	145												Test started at 8:00
8:30			2955	3.25	275	1.00	74	174	144	77		248	69	54	72	2862.6	226486	583	1.52	7190	239.7	226	185	132	13.6										
9:00			2955	275	250	1.75	78	144	168	80		246	60	54	65	2871.0	229819	521	1.36	6666	222.2	226	95	15.6	16.1	3.6	0.0	0.6	25.4	8.6	0.6	61.3	116.2	111.3	
9:30	86.00	Stand-by loss, Coal, Lbs, 1925; Ashes, 1375	2950	250	225	225	80	208	211	83		252	60	54	66	2881.1	233248	626	0.99	6858	228.6	260	55	7.9	8.2	5.0	0.0	0.8	21.0	5.8	0.0	67.4	87.0	84.0	Fire raked.
10:00			2948	3.75	325	1.60	73	238	230	63		276	59	54	63	2890.0	236802	632	0.46	7108	236.9	228	185	4.9	5.0	4.0	0.0	0.6	23.0	6.6	1.1	64.7	107.3	102.8	Fire raked.
10:30			2946	1.75	1.50	1.50	67	268	264	60	500	248	57	54	60	2899.1	240097	564	1.25	6590	219.7	208	25	15.4	15.6										
11:00	14.25		2945	2.75	225	225	73	284	272	60	510	248	66	53	60	2908.2	243709	564	0.51	7224	240.8	238	65	2.3	2.3										Fire raked.
11:30			29.43	350	335	225	77	360	284	64	500	260	57	53	62	2917.8	247289	595	1.08	7160	238.7	238	145	5.9	6.0										
12:00			2942	375	3.25	2.00	85	323	291	71	610	303	58	53	78	2927.0	250707	570	1.06	6836	227.9	234	185	12.6	12.9	2.0	0.0	0.6	27.2	9.0	1.2	60.0	129.9	124.0	
12:30			2942	2.00	215	150	86	346	305	67	700	276	56	53	61	2936.1	254059	564	1.87	6704	223.5	226	0	15.6	15.8	2.0	0.0	0.4	26.6	9.4	2.8	58.8	146.5	137.7	
1:00			29.41	316	300	175	96	345	316	67	[illegible]5	27[illegible]	57	54	62	2945.5	257765	583	0.40	7412	247.1	246	95	0.0	0.0	4.0	0.0	0.8	25.4	6.1	0.0	63.7	102.3	99.2	Fire raked.
1:30	38.25		29.40	375	325	2.00	93	354	3[illegible]3	70	620	272	58	54	65	2955.0	261208	589	1.80	6886	229.5	234	185	7.9	8.1										
2:00			2939	3.15	300	2[illegible]5	79	374	322	74	720	317	58	54	67	2964.0	264526	558	1.56	6636	221.2	224	165	15.5	15.9										
2:30			29.37	3.25	300	1.75	78	378	330	75	980	358	60	56	72	2973.2	267923	570	1.80	6794	226.5	222	185	14.2	14.6										
3:00	24.75		29.36	5.00	4.25	2.50	104	376	326	78	1025	361	60	56	71	2982.8	271174	545	2.38	6502	216.7	212	145	15.2	15.8	4.0	0.0	0.6	27.0	6.5	0.6	61.3	114.9	111.0	Fire raked One side poked down
3:30			29.36	325	300	2.00	106	389	322	79	1080	368	63	56	74	2991.9	274508	564	2.46	6668	222.3	228	95	12.3	12.8										
4:00	21.0	330	29.35	2.90	300	2.00	108	405	334	79	960	343	64	57	69	3001.4	278078	589	1.28	7140	238.0	234		7.9	8.2										Test stopped at 4:00
Aver			29.43	3.3	2.90	2.00	87	303	269	71	740	286	59	54	66			574	1.36	6898	229.9	230	122	10.4	10.7	3.5	0.0	0.6	25.1	7.4	0.9	61.5	114.7	109.9	
Total	177.5	330																9187	21.78	110374															

FIG. 9.

APPENDIX

Table I. Properties of Gases

	H_2.	CO.	CH_4.	C_2H_4.	CO_2.	N_2.	O_2.	AIR.
Wt. per cu. ft. 32° F., 29.921″........	0.00561	0.07810	0.04488	0.07949	0.12343	0.07842	0.08921	0.08073
Wt. per cu. ft. 62° F., 30″ hg.........	0.00530	0.07381	0.04238	0.07513	0.11665	0.07411	0.08432	0.07630
Vol. of 1 pound, 32° F. 29.921″..........	178.23	12.804	22.301	12.580	8.102	12.752	11.209	12.387
Vol. of 1 pound 62° F. 30″hg..........	188.58	13.548	23.597	13.311	8.574	13.493	11.806	13.107
B.t.u. per pound High Value	61524.0	4395.6	24021.0	21222.0	.....	.....	.....	.....
B.t.u. per pound Low Value...........	51804.0	4395.6	21592.8	19834.2	.....	.....	.....	.....
B.t.u. per cu. ft. 62°, 30″ High........	326.24	324.45	1018.0	1594.3	.....	.....	.....	.....
B.t.u. per cu. ft. 62° 30″ Low........	274.78	324.45	915.08	1490.1	.....	.....	.....	.....
C_p	3.409	0.245	0.593	0.404	0.216	0.244	0.2175	0.2375
C_v	2.406	0.173	0.467	0.332	0.171	0.173	0.155	0.1689
γ	1.417	1.416	1.27	1.144	1.165	1.409	1.403	1.406

Table II. Methane, CH_4.

High Heat Value of various percents of Marsh Gas, Methane, in one Cubic Foot at 62°F. and 30″Hg.

%	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
0	0.0	1.02	2.04	3.05	4.07	5.09	6.11	7.13	8.14	9.16
1	10.18	11.20	12.22	13.23	14.25	15.27	16.29	17.31	18.32	19.34
2	20.36	21.38	22.40	23.41	24.43	25.45	26.47	27.49	28.50	29.52
3	30.54	31.56	32.58	33.59	34.61	35.63	36.65	37.67	38.68	39.70
4	40.72	41.74	42.76	43.77	44.79	45.81	46.83	47.85	48.86	49.78

Table III. Methane, CH_4.

Low Heat Value of various percents of Marsh Gas, Methane, in one Cubic Foot at 62°F. and 30″Hg.

%	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
0	0.0	.92	1.83	2.75	3.66	4.58	5.49	6.41	7.32	8.24
1	9.15	10.07	10.98	11.90	12.81	13.73	14.64	15.56	16.47	17.39
2	18.30	19.22	20.13	21.05	21.96	22.88	23.79	24.71	25.62	26.54
3	27.45	28.37	29.28	30.20	31.11	32.03	32.94	33.86	34.77	35.69
4	36.60	37.52	38.43	39.95	40.26	41.18	42.09	43.01	43.92	44.84

Table IV. Carbon Monoxide, CO.

Heat Value of, for various percents per Cubic Foot. At 62°F and 30 Hg.

%	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
0	0.0	0.3	0.6	1.0	1.3	1.6	1.9	2.3	2.6	2.9
1	3.2	3.6	3.9	4.2	4.5	4.9	5.2	5.5	5.8	6.2
2	6.5	6.8	7.1	7.5	7.8	8.1	8.4	8.8	9.1	9.4
3	9.7	10.1	10.4	10.7	11.0	11.4	11.7	12.0	12.3	12.7
4	13.0	13.3	13.6	14.0	14.3	14.6	14.9	15.2	15.6	15.9
5	16.2	16.5	16.9	17.2	17.5	17.8	18.2	18.5	18.8	19.1
6	19.5	19.8	20.1	20.4	20.8	21.1	21.4	21.7	22.1	22.4
7	22.7	23.0	23.4	23.7	24.0	24.3	24.7	25.0	25.3	25.6
8	26.0	26.3	26.6	26.9	27.3	27.6	27.9	28.2	28.6	28.9
9	29.2	29.5	29.8	30.2	30.5	30.8	31.1	31.5	31.8	32.1
10	32.4	32.8	33.1	33.4	33.7	34.1	34.4	34.7	35.0	35.4
11	35.7	36.0	36.3	36.7	37.0	37.3	37.6	38.0	38.3	38.6
12	38.9	39.3	39.6	39.9	40.2	40.6	40.9	41.2	41.5	41.9
13	42.2	42.5	42.8	43.2	43.5	43.8	44.1	44.4	44.8	45.1
14	45.4	45.7	46.1	46.4	46.7	47.0	47.4	47.7	48.0	48.3
15	48.7	49.0	49.3	49.6	50.0	50.3	50.6	50.9	51.3	51.6
16	51.9	52.2	52.6	52.9	53.2	53.5	53.9	54.2	54.5	54.8
17	55.2	55.5	55.8	56.1	56.5	56.8	57.1	57.4	57.8	58.1
18	58.4	58.7	59.0	59.4	59.7	60.0	60.3	60.7	61.0	61.3
19	61.6	62.0	62.3	62.6	62.9	63.3	63.6	63.9	64.2	64.6
20	64.9	65.2	65.5	65.9	66.2	66.5	66.8	67.2	67.5	67.8
21	68.1	68.5	68.8	69.1	69.4	69.8	70.1	70.4	70.7	71.1
22	71.4	71.7	72.0	72.4	72.7	73.0	73.3	73.7	74.0	74.3
23	74.6	74.9	75.3	75.6	75.9	76.2	76.6	76.9	77.2	77.5
24	77.9	78.2	78.5	78.8	79.2	79.5	79.8	80.1	80.5	80.8
25	81.1	81.4	81.8	82.1	82.4	82.7	83.1	83.4	83.7	84.0
26	84.4	84.7	85.0	85.3	85.7	86.0	86.3	86.6	87.0	87.3
27	87.6	87.9	88.3	88.6	88.9	89.2	89.5	89.9	90.2	90.5
28	90.8	91.2	91.5	91.8	92.1	92.5	92.8	93.1	93.4	93.8
29	94.1	94.4	94.7	95.1	95.4	95.7	96.0	96.4	96.7	97.0
30	97.3	97.7	98.0	98.3	98.6	99.0	99.3	99.6	99.9	100.3
31	100.6	100.9	101.2	101.6	101.9	102.2	102.5	102.9	103.2	103.5
32	103.8	104.1	104.5	104.8	105.1	105.4	105.8	106.1	106.4	106.7
33	107.1	107.4	107.7	108.0	108.4	108.7	109.0	109.3	109.7	110.0
34	110.3	110.6	111.0	111.3	111.6	111.9	112.2	112.6	112.9	113.2

Table V. Hydrogen, H_2.

Heat Value of, for various percents per Cubic Foot. High Value, at 62°F and 30″Hg

%	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
0	0.0	0.3	0.7	1.0	1.3	1.6	2.0	2.3	2.6	2.9
1	3.3	3.6	3.9	4.2	4.6	4.9	5.2	5.5	5.9	6.2
2	6.5	6.9	7.2	7.5	7.8	8.2	8.5	8.8	9.1	9.5
3	9.8	10.1	10.4	10.8	11.1	11.4	11.7	12.1	12.4	12.7
4	13.0	13.4	13.7	14.0	14.3	14.7	15.0	15.3	15.6	16.0
5	16.3	16.6	16.9	17.3	17.6	17.9	18.2	18.6	18.9	19.2
6	19.6	19.9	20.2	20.5	20.9	21.2	21.5	21.8	22.2	22.5
7	22.8	23.1	23.5	23.8	24.1	24.4	24.8	25.1	25.4	25.7
8	26.1	26.4	26.7	27.0	27.4	27.7	28.0	28.4	28.7	29.0
9	29.4	29.7	30.0	30.3	30.7	31.0	31.3	31.6	32.0	32.3
10	32.6	33.0	33.3	33.6	33.9	34.3	34.6	34.9	35.2	35.6
11	35.9	36.2	36.5	36.9	37.2	37.5	37.8	38.2	38.5	38.8
12	39.1	39.5	39.8	40.1	40.5	40.8	41.1	41.4	41.8	42.1
13	42.4	42.7	43.1	43.4	43.7	44.0	44.4	44.7	45.0	45.3
14	45.7	46.0	46.3	46.7	47.0	47.3	47.6	48.0	48.3	48.6
15	48.9	49.3	49.6	49.9	50.2	50.6	50.9	51.2	51.5	51.9
16	52.2	52.5	52.8	53.2	53.5	53.8	54.1	54.5	54.8	55.1
17	55.5	55.8	56.1	56.4	56.8	57.1	57.4	57.7	58.1	58.4
18	58.7	59.0	59.4	59.7	60.0	60.4	60.7	61.0	61.3	61.7
19	62.0	62.3	62.6	63.0	63.3	63.6	63.9	64.3	64.6	64.9
20	65 2	65.6	65.9	66.2	66.6	66.9	67.2	67.5	67.9	68.2
21	68.5	68.8	69.2	69.5	69.8	70.1	70.5	70.8	71.1	71.4
22	71.8	72.1	72.4	72.8	73.1	73.4	73.7	74.1	74.4	74.7
23	75.0	75.3	75.6	76.0	76.3	76.7	77.0	77.3	77.6	78.0
24	78.3	78.6	79.0	79.3	79.6	79.9	80.3	80.6	80.9	81.2
25	81.6	81.9	82.2	82.5	82.9	83.2	83.5	83.8	84.2	84.5
26	84.8	85.1	85.5	85.8	86.1	86.5	86.8	87.1	87.4	87.8
27	88.1	88.4	88.7	89.1	89.4	89.7	90.0	90.4	90.7	91.0
28	91.3	91.7	92.0	92.3	92.7	93.0	93.3	93.6	94.0	94.3
29	94.6	94.9	95.3	95.6	95.9	96.2	96.6	96.9	97.2	97.5
30	97.9	98.2	98.5	98.8	99.2	99.5	99.8	100.1	100.5	100.8
31	101.1	101.4	101.8	102.1	102.4	102.8	103.1	103.4	103.7	104.1
32	104.4	104.7	105.0	105.4	105.7	106.0	106.3	106.7	107.0	107.3
33	107.6	108.0	108.3	108.6	108.9	109.3	109.6	109.9	110.3	110.6
34	110.9	111.2	111.6	111.9	112.2	112.5	112.9	113.2	113.5	113.8

Table VI. Hydrogen, H_2.

Heat Value of, for various percents per Cubic Foot. Low value, at 62F° and 30″Hg.

%	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
0	0.0	0.3	0.5	0.8	1.1	1.4	1.6	1.9	2.2	2.5
1	2.7	3.0	3.3	3.6	3.8	4.1	4.4	4.7	4.9	5.2
2	5.5	5.8	6.0	6.3	6.6	6.9	7.1	7.4	7.7	8.0
3	8.2	8.5	8.8	9.1	9.3	9.6	9.9	10.2	10.4	10.7
4	11.0	11.3	11.5	11.8	12.1	12.4	12.6	12.9	13.2	13.5
5	13.7	14.0	14.3	14.6	14.8	15.1	15.4	15.7	15.9	16.2
6	16.5	16.8	17.0	17.3	17.6	17.9	18.1	18.4	18.7	19.0
7	19.2	19.5	19.8	20.1	20.3	20.6	20.9	21.2	21.4	21.7
8	22.0	22.2	22.5	22.8	23.1	23.4	23.6	23.9	24.2	24.5
9	24.7	25.0	25.3	25.6	25.8	26.1	26.4	26.7	26.9	27.2
10	27.5	27.8	28.0	28.3	28.6	28.9	29.1	29.4	29.6	29.9
11	30.2	30.5	30.8	31.1	31.3	31.6	31.9	32.1	32.4	32.7
12	33.0	33.2	33.5	33.8	34.1	34.3	34.6	34.9	35.2	35.4
13	35.7	36.0	36.3	36.5	36.8	37.1	37.4	37.6	37.9	38.2
14	38.5	38.7	39.0	39.3	39.6	39.8	40.1	40.4	40.7	40.9
15	41.2	41.5	41.8	42.0	42.3	42.6	42.9	43.1	43.4	43.7
16	44.0	44.2	44.5	44.8	45.1	45.3	45.6	45.9	46.2	46.4
17	46.7	47.0	47.3	47.5	47.8	48.1	48.4	48.6	48.9	49.2
18	49.5	49.7	50.0	50.3	50.6	50.8	51.1	51.4	51.7	51.9
19	52.2	52.5	52.8	53.0	53.3	53.6	53.9	54.1	54.4	54.7
20	55.0	55.2	55.5	55.8	56.1	56.3	56.6	56.9	57.2	57.4
21	57.7	58.0	58.3	58.5	58.8	59.1	59.4	59.6	59.9	60.2
22	60.5	60.7	61.0	61.3	61.6	61.8	62.1	62.4	62.6	62.9
23	63.2	63.5	63.7	64.0	64.3	64.6	64.8	65.1	65.4	65.7
24	65.9	66.2	66.5	66.8	67.0	67.3	67.6	67.9	68.1	68.4
25	68.7	69.0	69.2	69.5	69.8	70.1	70.3	70.6	70.9	71.2
26	71.4	71.7	72.0	72.3	72.5	72.8	73.1	73.4	73.6	73.9
27	74.2	74.5	74.7	75.0	75.3	75.6	75.8	76.1	76.4	76.7
28	76.9	77.2	77.5	77.8	78.0	78.3	78.6	78.9	79.1	79.4
29	79.7	80.0	80.2	80.5	80.8	81.1	81.3	81.6	81.9	82.2
30	82.4	82.7	83.0	83.3	83.5	83.8	84.1	84.4	84.6	84.9
31	85.2	85.5	85.7	86.0	86.3	86.6	86.8	87.1	87.4	87.7
32	87.9	88.2	88.5	88.8	89.0	89.3	89.6	89.9	90.1	90.4
33	90.7	91.0	91.2	91.5	91.8	92.1	92.3	92.6	92.9	93.2
34	93.4	93.7	94.0	94.3	94.5	94.8	95.1	95.4	95.6	95.9

Conclusions.

The following conclusions are drawn as a result of this test:

1. The operation of the installation on the whole was very satisfactory.

2. The operation, so far as the fuel consumption was most economical, for a plant of this size. As a matter of fact, the results showed a lower fuel consumption than is attained by producer plants of this size in England.

3. The operation at three-quarter load was very good, and the economy was about as it should be, showing an increased fuel consumption per unit of power developed over that at full load.

4. The operation of the installation under variable load was extremely satisfactory, so far as continuity of operation and fuel consumption were concerned.

5. The producer was able to adjust itself to make gas to meet varying condition most satisfactorily.

6. The grate efficiency of the generator was comparatively high.

7. The proportions of the generator, so far as the area of the fuel column and the height of same are concerned, were satisfactory.

8. The sectional area was ample for a 15 horse power producer

9. The poke holes were well designed, so that one could reach every part of the fuel column except in the case where one poke hole was omitted.

10. The magazine directly beneath the hopper was too short and did not contain a sufficient amount of coal for reserve.

11. The design of this generator without a grate was satisfactory.

12. The jacket on the generator was effective in heating the air successfully to take up the proper amount of moisture.

13. The vaporizer was satisfactory in that all the water supplied to it through the regulator was evaporated.

14. The vaporizer in this instance did not offer too great a resistance to the passage of air through the same.

15. The vaporizer was efficient in reducing the temperature of the gases leaving the generator before they entered the scrubber.

16. The scrubber was well proportioned and cleaned the gas most efficiently.

17. The water regulator served to admit water in proportion to the power developed by the engine.

18. The coal consumption per hour was nearly constant and apparently independent of the power developed for the load factors used.

DISCUSSION.

Mr. A. R. Swoboda: I do not quite understand what is meant by grate efficiency.

Prof. MacFarland: The term *grate efficiency* is perhaps a misnomer, because there is no grate in the producer described. It represents the percentage of heat supplied to the generator that was utilized. By taking the weight of the ash and determining the heating value of the ash the heat rejected in the ash was determined. The ash represented quite a lot of good coal; for in some cases, in poking the producer, there would be a handful of good coal which would run down through, and having no grate to retain it, it was lost. I would not allow that coal to be used over again. Everything that went into the hopper was measured and we did not use anything the second time. It would be hardly fair to charge up the number of pounds by considering the weight of the ash that was in the coal and consider the difference good coal. Therefore, the heating value of the ash was determined in the same manner as the heating value of the coal. We took a sample in the same regular way and then multiplied the weight of the ash removed by its heating value as determined from analysis, and got a certain number of heat units; dividing that by a certain number of heat units supplied in the coal to the hopper, it gave a value for the first day of 20% subtracting that from 100% gives the grate efficiency of 80%. It seems like a common sense value.

Mr. Paul R. Brooks: Is not the grate efficiency a matter of attendance entirely?

Prof. MacFarland: Yes, almost entirely. Just one extra poke would make a difference in the coal in the ashes. The grate efficiency could possibly be maintained to 90 per cent.

Mr. J. H. Warder, M.W.S.E.: What is the objection to having a grate?

Prof. MacFarland: The objection to a grate is it has a tendency to burn out, and the poking adds complications. There are no greater objections other than these. There is a tendency in England to have small producers without grates. In producers of 25 h. p., where the fuel column does not taper down to a diameter of 8 inches, I find the air coming in from all sides, leaving a small cone at the center where air does not get in at all. A better distribution of air is made by having a grate for a producer of 18 in. in diameter; for a smaller size of producer I would not deem it advisable to have a grate.

Mr. Swoboda: Referring again to the matter of grate, how does the solid grate compare with the open grate?

Prof. FacFarland: Perhaps Mr. Atkinson, who is the designer of this producer, can tell us something about this, for since these tests were made he has designed a raised grate.

Mr. C. J. Atkinson: In regard to the matter of grates: I found that in the small size of producer, where there was an absence of fire bars, there was also an absence of complications which counteracted the value of the fire bars. In a small producer it is not so much a question of coal economy as it is reliability, and with a small producer I found that the only way to get reliability was with a solid grate. With a large size producer the consumption of coal is a greater factor, and there you have to plan on saving as closely as possible. I have lately brought out a new grate which has a central air draft. The grate itself represents the same principle as a solid table, but it is made so that it can be raised vertically, and that vertical movement tends to clean the grate ashes, so it is not necessary to poke or rake the fire from the top as in the small producer. Therefore we get the same arrangement, but with an increased efficiency. Where there are fire bars, as in boilers, the fire bars will not always stand the high temperature; and when the fireman pokes the fire from the top he sometimes breaks the bars, which means considerable expense in replacing them.

Mr. Swoboda: The reason I asked in regard to the grate was that it occurred to me the ordinary form of grate was not suitable for that particular purpose; that small holes were liable to appear, and therefore the correct quantity of gas would not be produced. It has seemed to me that a grate more of the nature of a solid grate would be more suitable than an open grate.

Mr. Atkinson: The solid grate certainly gives a higher efficiency for that and other reasons, where you use a perforated grate large quantites of small unburned fuel may fall through in places whilst in

other places ashes will accumulate, thus increasing the air supply in the clean parts and so forming a cavity.

Mr. Brooks: What happens when you over-drive a producer?

Prof. MacFarland: The first thing in over-driving is to increase the quantity of the gas and decrease its quality.

Mr. Brooks: In what respect?

Prof. MacFarland: The decrease of carbon monoxide. It takes a certain time to change the carbon dioxide; there has to be a surface contract of the gas with the hot coal, and as you over-drive the producer you increase the velocity and there is not the desirable baffling effect on the gases as they go through the coal.

Mr. Chas. C. Robbins: It may be interesting to hear from another point of view—from the standpoint of a consumer of power. The company with which I am connected put in a suction gas producer in the spring of 1907, as an experiment. The engine connected with this producer is 35 h. p. The plant has been in use continuously since its installation and we have had very satisfactory results. At first, as might be expected, we had considerable trouble, due to lack of knowledge of the operations and to the very unsatisfactory supply of information available. The plant has been driving a cold storage outfit—compressor, etc.,—and, as already stated, we have been using about 35 h. p. Our consumption of coal runs about 1.25 lb. of coal per h. p. hr. The time of operation has not been uniform; some days we would run five hours, other days ten hours, etc., and sometimes we have not run for a week, but we have never had any trouble in getting gas in about 30 minutes; we have never had any trouble with the operation of the plant so far as the gas was concerned or the efficiency of the producer. The gas engine has caused some trouble at times, but the troubles have always been from lack of knowledge on the part of the engineer. I find very few engineers who know anything about producer gas plants, and therefore the scarcity of skilled labor of that kind, is one of the problems we have to consider when installing such plants.

So far as our company is concerned, we are satisfied that the producer gas plant is the coming power for stationary engines, particularly where the load is anywhere near uniform.

Mr. W. J. Miskella: JUN.M.W.S.E.: I would ask Prof. MacFarland if he will explain the seal pot arrangement, particularly the angle pipe.

Prof. MacFarland: Referring to Fig. 2, that angle was in the bottom of the vaporizer so that if an overflow of water should occur, it would be drained out. In use, that pot will be closed and there will be no water passing down there, but if any water *should* get through, it could be drained out.

Mr. George M. Mayer, M.W.S.E.: Judging from Prof. MacFarland's paper, he must have made a good many tests. I would ask whether he has made engine tests using city gas, and how the cost would compare with an engine of the same size, including cost of installation, etc.

Prof. MacFarland: I do not wish to go into the question of comparative cost at this time. That will be taken up some time in the future, when very complete records which are being made at the present time on a 100 h. p. installation, will be presented to this Society,—probably in the course of six months. At that time everything will be considered, including the rent of the room, etc., and I shall be glad then to show comparative costs.

Mr. Mayer: The reason I asked that question was that I thought the cost of maintenance would be very high.

Prof. MacFarland: Perhaps Mr. Robbins will give us some information along that line.

Mr. Robbins: We have to charge our producer once a day. It takes, on an average, 475 to 495 pounds of coal per day, as we run the producer. I believe that the total time required of the attendant, per day of ten hours, is about 1 hour and 45 minutes. The man who is doing that work is unskilled, and has no theoretical knowledge. He was running my automobile, does not know the first principles of mechanics, but is able to keep this plant running. I believe 1.5 hours a day for a skilled man is all that is necessary for a plant of 50 to 100 h. p. I pay the man I have referred to $18.00 per week.

Mr. A. W. Moseley, M.W.S.E.: I notice that on May 21st the water consumed by the scrubber was 3,534 lbs., but on the next day 9,178 lbs. of water were used in the scrubber. Was this difference in water consumption accidental or necessary?

Prof. MacFarland: That was not essential at all, and was possibly accidental. No attention was given to that. The water supply was a little irregular, and the pressure was variable. In a large plant the consumption of water would be an important item.

Mr. Brooks: I would ask if that water could be used over again.

Prof. MacFarland: Yes, if one wished to do so.

Mr. Mayer: Was the gas clean, or more like city gas?

Prof. MacFarland: So far as the engine was concerned the gas was sufficiently clean—about as you would find city gas, I think. It is not hard to clean producer gas. I suspect our scrubbers are entirely too cumbersome, and we hope to have a better design sometime.

Mr. H. Gansslen, M.W.S.E.: I would like to know just what the physical or mechanical properties of the German coals are that make them better adapted for use in producers. I was under the impression that the main reason why the producer was not being used so much here was the cheapness of coal here; in Germany coal is much more expensive, and many years ago they were compelled to pay more attention to economy, as far as coal consumption goes, this being at the same time a good reason for the general use of producers and gas engines there.

Prof. MacFarland: That is due, I judge, to the lack of ash. The foreign coals contain a smaller quantity of ash, and consequently a less quantity of clinker will be formed.

Mr. Gansslen: The percentage of hydrogen in these tests is rather

low. I would like to know whether this vaporizer would be capable of evaporating the maximum quantity that could be admitted, and yet have the producer work satisfactorily,—that is,—not lower the temperature in the fire too much? I have noticed in some types of producers that it was practically impossible to get any large percentage of hydrogen; in other words, the air could not be heated sufficiently to convey a sufficient amount of water to the fire to give the maximum percentage of hydrogen and lower the percentage of the inert nitrogen thereby.

Prof. MacFarland: That question is a very pertinent one, for I have had that experience myself—a vaporizer on a producer that was not of sufficient capacity—but here the vaporizer is increased, so to speak, from the fact that the air comes to the vaporizer hot, and without doubt this vaporizer will take care of possibly four times as much water as was supplied. If you will refer to the temperatures in the Table, Fig. 6, column 8, you will find that the average temperature of the air going to the jacket was 120 deg. F. The air as it leaves, goes to the vaporizer during the entire day at an average temperature of 327 deg. F., so the temperature of the air was increased on an average of 200 deg. in the jacket of the producer. The temperature of the air at fuel column was 277 deg. F.; the gas as it left the vaporizer to go to the scrubber had a temperature of 326 deg. and had a larger quantity of water been supplied to the vaporizer it would have been vaporized and the air would have taken it up successfully. In any case, if a vaporizer is not of sufficient capacity one can always put the water in the base, and perhaps that is as desirable a form. I have the results of a producer being built in Chicago at the present time where just such a method is used. The steam is supplied at the base of the generator, and there combines with the air. In that producer it was shown that 11.5 pounds of coal had the equivalent of 0.83 of a gallon of high grade gasoline. The coal had the equivalent of about 128,000 B. t. u., whereas the gasoline used had an equivalent of about 100,000 B. t. u. From that you have to take the efficiency of the producer, which is between 70 and 80 per cent. In this way we get a comparison between producer gas for heating purposes and high grade gasoline. Comparing the cost, in one case you are paying 23c. per gallon for the gasoline, and that leaves 19c. for the gasoline consumed, and the coal costs 3c. As compared to cost we have a ratio of 6 to 1.

Mr. Gansslen: Do you consider the uniformity of the gas, which is probably largely governed by the regulator, sufficient to make the gas useful for heating purposes such as you mention,—that is, will the gas burned in a suitable open burner give approximately the same rich flame right along? For industrial heating purposes in canning and can factories it is practically out of the question to get satisfactory results with variations in the quality of gas, which, as far as I am experienced, amount often to 30 per cent. and more with producer gas without much warning, and are largely due to the varia-

tions in the load on the producer. This difficulty is probably not of such grave consequences where the gas is used for power purposes, in which case a water regulator is not needed so badly.

Prof. MacFarland: I regard the water regulator as a very essential part of the producer, and unless you have one you cannot insure satisfactory results. But with most any regulator you can regulate closely.

Mr. C. M. Garland, U. of I.; Urbana, Ill., (by letter): Referring to Professor H. B. MacFarland's paper on the "Test of a Small Suction Gas Producer Plant," it might be of interest to bring up the question as to whether or not the hydrogen in the producer gas is really a valuable constituent when the gas is to be used for power purposes.

A recent article by Mr. G. F. M. Tait in Cassier's Magazine gives the results of some experiments which seem to indicate that it is not.

The argument in support of this conclusion which is in turn supported by the experiments, is somewhat as follows: A producer plant using steam to keep down the temperature of the combustion zone, prevent the formation of clinker and to enrich the gas formed with hydrogen, labors under a number of disadvantages. In the first place the hydrogen content of the gas is high and any variation in the quantity of the hydrogen which is likely to occur at any time due to change in the steam supply, or in the condition of the fuel bed, produces a marked change in the operation of the engine, and consequently tends to make the operation of the plant unreliable. Again, the principal combustible constituents of the gas are CO and the H. The properties of these two gases are very different. Hydrogen possesses probably ten times the affinity of oxygen that the CO does. If these gases, CO and H are used in the cylinder together, it is evident that if ignition and compression are correct for the CO, they will not be correct for the H. And the reverse is also true. The H being very inflamable will not withstand a high compression. Consequently, a gas consisting largely of H must be used in an engine with low compression and with a resulting low efficiency. The CO, however, is not so inflammable as the H, and permits of high compression, with the resulting high engine efficiency.

From this it might seem advisable, as far as the engine is concerned, to eliminate the H from the gases. In order to operate the producer efficiently, however, it has been found necessary to keep down the temperature of the fuel bed, in order to prevent excessive loss of heat. This is accomplished in the ordinary producer by feeding steam to the producer together with the air. The excessive heat is taken up in the formation of H which is later given out by the combustion of this H in the engine cylinder. In order, therefore, to eliminate the H from the gases going to the engine cylinder, it is necessary to lower the temperature in the producer by some other means. This was accomplished in the tests referred to above by using the exhaust gases from the engine to dilute the air entertaining the producer. The gas formed under this condition contains CO as practi-

cally the only combustible constituent, and possesses a low calorific value (about 90 B. t. u. per cubic foot). The tests show an increase in the efficiency of the engine, resulting from the use of this gas. This is partly due to the use of higher compression and possibly to the poor quality of the gas, which instead of exploding at the beginning of the stroke with a resulting high temperature and waste of heat to the cooling water (which is the case with a gas high in H), burns slowly so that the heat is added as the work of expansion proceeds, and less waste to the jacket water results. It is claimed that the use of this gas rendered the operation of the plant more reliable, as the absence of the H makes the gas more uniform in quality, and prevents premature ignition. No results are given as to the efficiency of the producer, but it is is probable that any loss in the efficiency of the producer will be more than compensated by the gain in the efficiency of the engine.

AUTHOR'S CLOSURE.

Since the preparation of this paper, I have received some very interesting data on the cost of operating a suction gas producer plant for the year 1907. The data was supplied by Mr. I. J. Babcock, Supt. of the A. B. Dick Co.'s Plant, 161 W. Jackson Boulevard, Chicago.

The power plant itself is unique in its installation, its method of operation and its efficient output. The installation consists of two units. The principal unit consists of a 100 h. p. gas producer, a 100 h. p. twin gas engine, direct connected to a 65 kw., 230 volt D. C. generator and a 200 ampere hour storage battery, 112 cells in a main battery and 26 end cells, used for both light and power purposes.

The secondary unit consists of a 75 h. p. gas producer and a 50 h. p. single gas engine, direct connected to a 35 kw., 230 volt. D. C. generator. The piping between the producers and engines is such that either engine can be operated from either producer. The small producer will make gas for the large engine for a period of six hours without showing signs of being overcrowded. The smaller engine can be operated when a small amount of power is needed. In case the plant is not in operation, light and power can be obtained for a period of time from the storage battery. In case of exceptionally heavy loads the two engines can be run in parallel to give 150 brake h. p.

The producers and engines were built and installed by the Minneapolis Steel & Machinery Co. The plant has been installed for nearly two years. Besides the regular generator, vaporizer, superheater and scrubber that go with every producer, there are auxiliary pieces of apparatus. The blower for starting up the generator is driven either by a 3 h. p. gas engine or by a 3 h. p. motor. There is a one-eighth h. p. motor on the night stack which is used when starting up the plant as the stack is very high, extending to the top of the building. The manometer board has connections so that one

can quickly test out the air resistance either through the generator, wet or dry scrubber, in case the plant does not operate properly.

The generator is charged at short intervals during the day, ranging from one-half to two hours, depending upon the load. The charge is always 70 pounds of coal. The attendant judges by the condition of the top of the fire when the charge should be put into the generator. The fire is always poked in the morning but is never pulled down so that the red coals show on the grate. The buckwheat anthracite coal is very completely burned, giving a high grate efficiency. The best results are obtained when the temperature of the saturated air going to the base of the generator is between 140 and 160 deg. Fah. At this temperature the air carries the right amount of moisture so that the producer gas does not contain too great a per cent of hydrogen.

During the year ending December 31, 1907, a total of 125,437 kilowatt hours service was obtained from this plant. The total operating expenses for the year was $1,586.46, which was divided as follows: Coal, $550.36; oil, $54.24; waste, $11.52; water, $168.00; gas, $33.32; attendance, $422.94; repairs, $224.50; insurance, $93.42; lamp renewals, $28.16.

The cost of operation per kilowatt hour in *cents*, was as follows: Coal, 0.439; oil, 0.043; waste, 0.009; water, 0.134; gas, 0.027; attendance, 0.337; repairs, 0.179; insurance, 0.075; lamp renewals, 0.022. Giving a low total cost of 1.26 cents per kilowatt hour.

One man looks after the plant, heating boilers, sprinkler system, and cleans and oils all the motors so that only half of his time is charged to the producer plant. While the plant is operated at only 52 per cent of its rated capacity, yet as compared with the Edison service that was used for five years it shows a profit of 10 per cent after charging off 10 per cent for depreciation.

SOME RESULTS DUE TO IMPROVEMENT IN BOILER AND FURNACE DESIGN

By A. Bement, M.W.S.E.

Presented December 18, 1907.

INTRODUCTORY.

This paper is not intended as a criticism of any style of boiler setting or scheme of furnace design. It is presented as one feature of an extended study to improve on present practice, which can be materially advanced. The reason comparison has been made with the Fisk Street Station of the Commonwealth Edison Company, is that this plant contains the best and latest design of Babcock & Wilcox boilers served by chain grate stokers, and burning bituminous coal screenings. Further, these units have many improvements and refinements, devised by engineers of the Commonwealth Edison and the Babcock & Wilcox Companies. This station owing to its superior turbine equipment makes steam at a much less cost than any other electric generating station in the world, thus the highest possible standard has been selected for comparison with the improved boiler.

The owner of this boiler was very well satisfied with its performance, Mr. Greene having made several tests before those reported in the paper were run. It was, however, considered desirable to have data comparable with that from other sources, because it was not sufficient that it had shown a very large reduction in fuel cost over other boilers in his plant, and it was for this reason that three additional tests were made with especial care, at which the author of this paper was present, rather in his own interest than as a representative of others. The Cedar Rapids & Iowa City Railway & Light Company engaged the Fuel Engineering Company as its representative, which company sent two men for the work, although the tests were more particularly under the direction of Mr. F. Chauvet, Fuel Engineer of the Fisk Street Station. The author was present, however, during the entire period of each test and watched every detail of the work, but none of the entries in the records were made by him. Mr. W. J. Greene was also present during nearly the entire period of each of the tests and also watched details closely.

The Fuel Engineering Company was represented by Messrs. F. B. Orr and J. Morowski, who, together with Mr. Chauvet, were assisted by employes in the station, who had experience in such work in making boiler tests for Mr. Greene. Thus the tests may be considered as having been jointly conducted by four independent and responsible parties, namely, the owner of the boiler, Mr. Chauvet, the Fuel Engineering Company and the designer of the boiler. After the tests were completed the records were compiled, and a summary of the observations drawn up and signed by Mr. Chauvet, the representative of the Fuel Engineering Company and the author.

Although in the appendix following the paper the source of the

data is given, yet it is well again to direct attention to the fact that the results for the Fisk Street performance is a compilation of data from different tests which the author has arranged in comparison with the results of three tests of the improved boiler in Tables 1 and 2. Data for the following values used therein were furnished by Mr. Chauvet, Fuel Engineer of the Fisk Street Station:

Horsepower,
CO_2 in combustion gases,
Final temperature of escaping gases,
Strength of draft.

In determining the loss of fuel in the refuse, special tests and samplings were made by him. All other data is from his reports of tests mentioned in the appendix.

The testing department of the Commonwealth Edison Co. furnished the following data:

Analysis of coal and refuse for both the Chicago and Cedar Rapids tests,
Loss in hot gases for all tests.

It was the object to have as many people participate in the work as possible. Thus the author appears before you more particularly as a compiler presenting conclusions drawn from evidence submitted, rather than as a writer offering experiments of his own, yet having a personal knowledge of all of the data employed, and it is trusted that the manner of presentation is such as to excite an active criticism, that the truth of the matter may appear without question. Therefore, in order that it may not seem intricate and complicated, it is well to say that the objects of the tests were to determine two things,

1. Did the presence of the tile roof insure complete combustion?

2. Did the presence of this tile roof injure the heat aborbing capacity of the boiler as compared to a similar boiler without a furnace roof?

Thus the inquiry concerned itself only with the matters of combustion and heat absorption, and that tests be strictly comparable, required that the two following conditions be the same for each boiler.

A. Temperature of combustion, or in other words per cent CO_2.

B. Horsepower developed in each boiler.

Thus it appears that stoker action could have no direct influence on the problem, because any measure of evaporation or efficiency secured, must be based on fuel actually taking part in the combustion process as distinct from the larger quantity fed to the stoker, a portion of which was lost in the ash pit refuse and therefore took no part in producing combustion. Thus comparative evaporation per pound of fuel must be based on that actually burned instead of on the quantity as fed, and if CO_2 differed, credit should be given to the test in which it was lowest. Thus CO_2 was lower in the case of improved boiler No. 10 and for this reason the Fisk Street boiler was at an advantage compared with it. Also, a considerable quantity of the fuel passed

into the refuse and did not enter into the combustion process, therefore the portion of fuel which entered into this process was very much smaller than that with the Fisk St. boiler. These facts should be kept in mind, otherwise confusion in discussing the paper will ensue.

The Paper as Presented.

It is now some six years since Mr. W. L. Abbott applied a tile furnace roof to Heine water tube boilers equipped with chain grate stokers in the Harrison Street power station of the Commonwealth Edison Company in Chicago, thereby producing what may be designated as a smoke proof furnace, to which the appearance of the four chimneys serving these boilers has since testified. The tiles used have been recently described.*

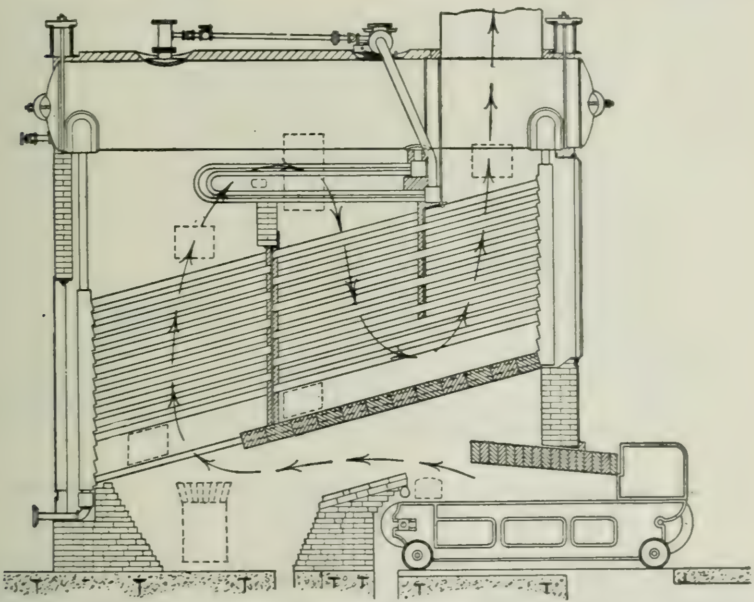

Fig. 1. Improved Boiler No. 10 with tile furnace roof which prevents gases coming directly in contact with tubes, and insures complete and smokeless combustion.

While the application of this tile roof to Heine and similar boilers has been quite general, its use in connection with the Babcock & Wilcox type has developed slowly, and it is only recently that marked progress has been made, although the advantage to be derived from such improvement was recognized in Chicago some five

*Journal W. S. E., December 1906, Vol. XI, Page 751.

years ago and its adoption recommended at that time. There are now available, however, some excellent data bearing on the subject, which it is the purpose of this paper to present.

About two years ago the Cedar Rapids & Iowa City Railway & Light Company, through Mr. W. J. Greene, Manager of its lighting department, contracted with the Stirling Consolidated Boiler Co. for an improved boiler after the author's design. It has now been in operation one year with very satisfactory results. It is known as No. 10 in the plant where it is in use, and will be hereinafter referred to by that number.

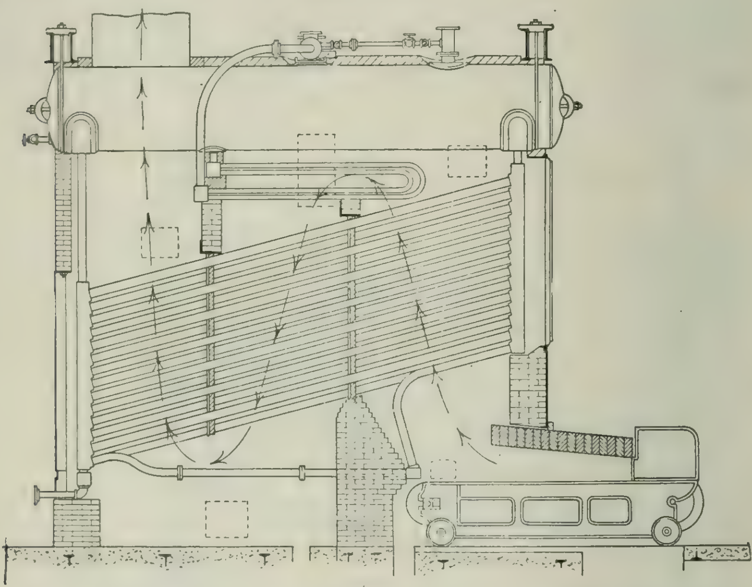

Fig. 2—Standard Babcock & Wilcox setting illustrating type of apparatus in Fisk Street Station.

Fig. 1 shows a boiler built to a second order for the same company by the Babcock & Wilcox Company, successor to the Stirling Consolidated Boiler Company. This second boiler which may be designated as No. 11, is equipped with a superheater. The first, or No. 10, has not as yet been so fitted, but it is the intention to do so in the near future, when turbines, now arranged for, are installed. Therefore Fig. 1, by considering the superheater absent, serves to show boiler No. 10 exactly as it is and was when tested, and with the superheater regarded a part of it, illustrates what this apparatus and future boilers will be.

Some standard for comparison is required to which the tests of boiler No. 10 are applicable and may be referred, therefore comparison is made with boilers in the Fisk Street electric gen-

erating station of the Commonwealth Edison Company in Chicago, a description of which appears together with other data, in an appendix hereto, although Fig. 2 shows a setting of this character. These Fisk Street boilers are selected because they are also served by chain grate stokers, and represent the very best and latest examples of apparatus designed by the builder, and are fired with bituminous coal.

A comparison between the Fisk Street boilers and this improved No. 10 is shown by a comparative heat balance, Table No. 1.

TABLE NO. 1.

Distribution of Heat From Coal Burned.

COMPARATIVE BASIS BETWEEN BOILERS.

	Improved Boiler No. 10.	Babcock & Wilcox Boilers at Fisk St Station.
Usefully employed in making steam	80.18%	68.32%
Lost in hot gases	18.34%	19.96%
Lost by radiation and unaccounted for	1.48%	
Lost by radiation		1.48%
Lost unaccounted for		10.24%
Total	100.00	100.00

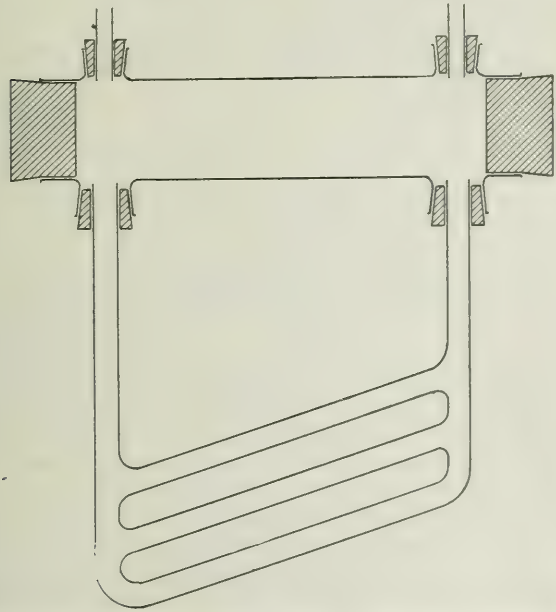

Fig 3.—Glass model representing boiler, used in experiments showing that manner of heat application had no effect on direction of circulation.

The results as to horsepower capacity produced by the boilers is equally as favorable to boiler No. 10 as that of efficiency, as set forth in Table No. 2.

TABLE No. 2.

COMPARATIVE CAPACITY.

	Improved Boiler No. 10	Fisk St Boiler based on average of 27 tests in appendix
Builders' horsepower rating	400	500
Heating surface in boiler, sq. ft.	4000	5200
Heating surface in superheater, sq. ft.	0.00	960
Heating surface, total sq. ft.	4000	6160
Grate area in sq. ft.	72	90
Height of chimney in feet	130	250
Draft over fire, in inches of water	0.262	0.713
Horsepower developed	624.5	812.3
Correct relative horsepower rating, on basis of 8.05% of work being done by superheater for Fisk Street boilers	400	543.7
Square feet of heating surface per horsepower developed on basis of 4000 and 5437 sq. ft.	6.40	6.69
Ratio of correct horsepower ratings	1.00	1.36
Ratio of horsepowers developed	1.00	1.30
Ratio of drafts at fire	1.00	2.72
Ratio of grate surfaces	1.00	1.25
Ratios of sq. ft. of heating surface required per horsepower developed	1.00	1.04
Ratios of horsepower developed with equal draft for both boilers	1.12	1.00
Ratio of capacities developed per sq. ft. of heating surface with equal draft for both boilers	1.53	1.00

The fact that the rate of working is nearly the same per unit of surface, notwithstanding the Fisk Street boilers have the advantage of a stronger draft above the fire by 272% is significant, showing the influence of the tile roof furnace on the rate at which the coal will burn, something which the author has observed many times before.

The complete data for the three tests which were made on boiler No. 10 are given in the appendix; that for the Fisk Street boilers, however, is compiled from a large number of tests and for that reason it is not feasible to present the large mass of matter which the full details would require, but complete explanation is given, and as an act of good faith, the number or

dates of these experiments are quoted as they appear in the test records.

One significant feature of tests Nos. 1, 2 and 3 of boiler No. 10 is the smallness of the combined item of heat lost by radiation and unaccounted for, which is 1.27%, 1.48% and 0.92%, respectively; not only is it uniform but very low in amount for each, much less than in any other tests with Western bituminous coal wherein an accurate determination of heating power of the coal was made, with which the author is familiar. This tends to show that combustion was complete, as further evidenced by the appearance of the chimney, which gives no indication whatever of smoke, except when fire is first started under the cold boiler, while on the other hand, the regular Babcock & Wilcox setting,

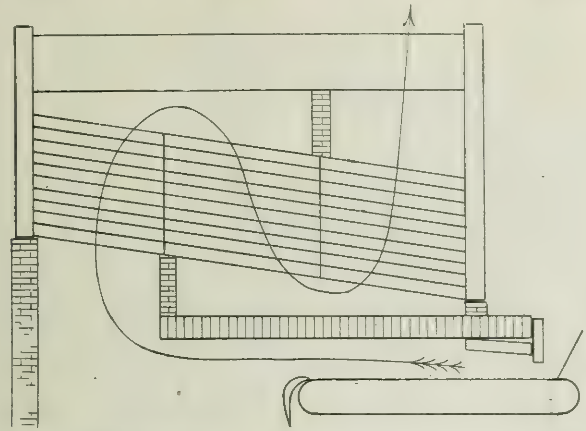

Fig. 4—Sketch showing original idea for furnace roof applied to Babcock & Wilcox boiler.

such as shown by Fig. 2, makes a serious amount of smoke, and resulting in the tests of the Fisk Street boilers, in a heat loss therein of 10.24%.

One of the things which has caused many people to hesitate in the adoption of the setting shown by Fig. 1, is a fear that discharging the heat from the furnace on the back or lower end of the boiler, would result in a "reversal" in the circulation of the water. No such indication, however, has been observed in this boiler No. 10, or with several others fitted with tile roof furnaces, but to test the matter the author employed a glass model Fig. 3, and experiments showed conclusively that the circulation proceeded in the same direction, whether the bank of tubes was heated at the back on the lower end, or at the front on the higher end.

In 1902, the idea of fitting a furnace roof to the Babcock & Wilcox boiler suggested itself to the author, and at that time he

made a rough sketch, a fac-simile of which is shown by Fig. 4. This scheme, however, was abandoned for obvious reasons, but recently, it has been proposed to again adopt it in connection with that boiler, using either a roof constructed by brick or tile arches, or composed of the special tiles surrounding the lower row of tubes. Therefore the author shows this scheme in its least objectionable form in Fig. 5, which consists in turning the boiler around and setting the stoker under the lower end. As compared to the design in Fig. 1, this plan has the following objectionable features:

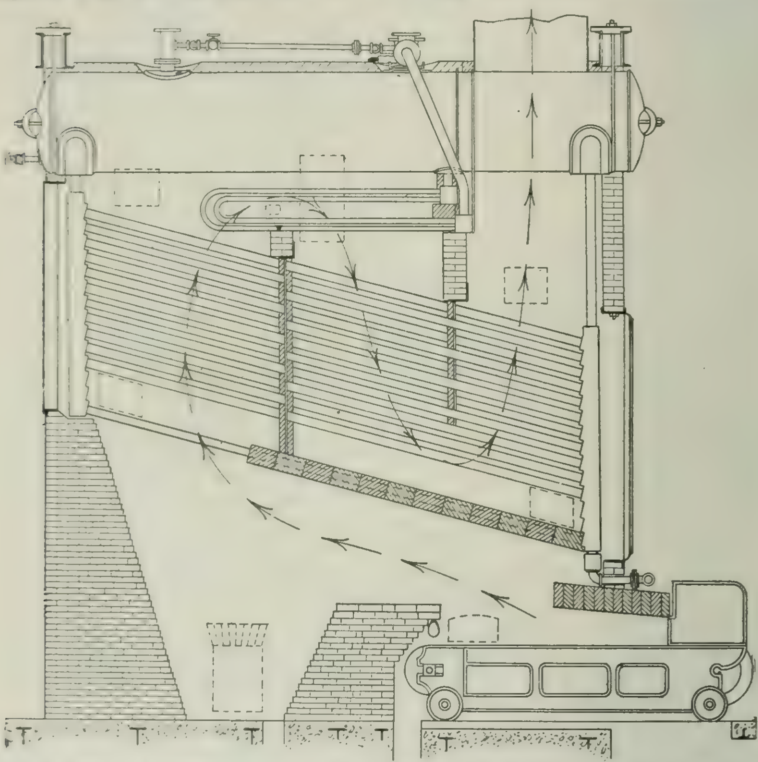

Fig. 5 —Plan for setting stokers under low end of boiler. Design requiring abnormally high setting walls.

1. It requires a greater height in the setting of some 4.5 feet with correspondingly larger investment and maintenance of the setting itself.
2. It increases the investment in boiler house building, owing to the necessity of its being 4.5 feet higher.
3. The cost of maintenance of the high and massive furnace walls will be much greater than in the other design.
4. The mud drum will be over the ignition arch.
5. If experience with "flat" and "sloping" ignition arches can

be taken as an indication, a furnace roof which rises toward the back, is not as effective in producing complete combustion as one which pitches downward toward the back as does that of Fig. 1.

APPENDIX.

To avoid encumbering the main portion of the paper with a large amount of detailed matter, the basis for the conclusions which have been presented in the foregoing is given in the following sections.

The object of these investigations was to determine the efficiency of combustion and heat absorption secured with the two different types of apparatus. For that reason coal produced by the Illinois Midland Coal Company, which corporation furnishes much of the fuel used in making steam with the Chicago boilers, was shipped to Cedar Rapids, Iowa, for use in tests of boiler No. 10. The setting of the stoker and the arrangement of the water back for this boiler at Cedar Rapids were adjusted in accordance with the requirements for burning Iowa

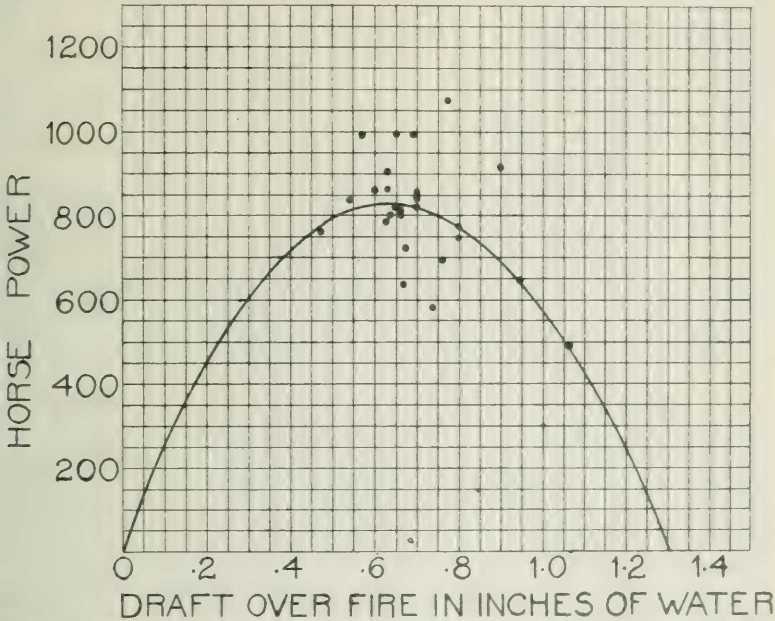

Fig. 6. Curve showing relation of horse-power to draft. Boilers of Fisk Street Station.

screenings which were considered to contain often as high as 35% ash, necessitating a large opening at the end of the grate under the water back for the exit of such an amount of refuse; therefore when the Illinois coal containing less than one-half as much ash was used in the tests, it required that either a large amount of fuel be allowed to enter the pit with the ash, or else leave a serious opening at the rear end of the grate at which air would enter in such volume as to so harmfully affect the result by loss of heat in the hot gases, as well as the horsepower capacity obtained, that the results would not be comparable with the performance of the Fisk Street boilers. Inasmuch, however, as the object of these tests did not in any way concern itself with fuel loss in the

refuse, its amount is entirely immaterial, because the inquiry did not embrace stoker action.

The results of the Fisk Street performance are compiled from a large number of tests, while those for the improved boiler No. 10 are from three tests given in Table No. 3.

THE COAL USED.

As before mentioned, it was desirable in making tests of boiler No. 10 at Cedar Rapids, to have the conditions as far as possible, correspond to those under which the Chicago boilers operated, therefore coal was shipped from one of the mines of the Illinois Midland Coal Company operating in the Springfield District of Illinois, which district supplies much of the coal burned under the Chicago boilers. The composition of this coal on the basis of pure coal and combustible, is given as follows:

	Pure Coal	Combustible
Carbon	74.86	89.50
Hydrogen, available	3.92	4.69
Sulphur, less S in Ash	4.86	5.81
Nitrogen	1.23	
Water of Combination	15.13	
Total Combustible	83.64	100.00
Total Non-Combustible	16.36	

Moisture and ash values are given in Table No. 3.

The tests from which the average for the efficiency value was compiled for the Fisk Street boilers, were made with the Illinois Midland coal. Those, however, supplying the average horsepower value are not all from such coal, a superior quality from the southern part of Illinois being used in a number of cases, and for this reason gave a higher capacity than would have been obtainable had the above coal only been used, but the value is employed nevertheless, as the figure of 812.3 is an average of certain twenty-seven tests which has been generally accepted as the representative capacity of the boilers.

DATA FOR EFFICIENCY, 18 TESTS.

The average efficiency based on coal as fed for the Fisk Street boilers is from eighteen tests Nos. 14, 14A, 14B, 15, 19, 20, 21, 23, 24, 25, 26, 27, 28, 34, 35, 36, 37 and 38 made between March 15th and June 25th, 1907, and the efficiency originally reported upon the basis of the specific heat of superheated steam as 0.75 has been recalculated, using this factor as 0.503, (as determined by Messrs. Osc. Knoblauch and Max Jakob, and reported in the Zeitschrift des Vereines deutscher Ingenieure, issues of January 19th and 26th, 1907, under the title of Relation of the Specific Heat Cp of Steam to Pressure and Temperature), which gave an average efficiency of 64.23%. The heating power of the coal as originally determined with the Parr calorimeter was somewhat too high, averaging 14.375 B. t. u. in the pure coal, which when corrected to the Mahler calorimeter, became 14.000, therefore the efficiency of 64.23 was corrected to 65.95%. Inasmuch, however, as the boilers on which these tests were made are fitted with a hopper at the front end of the chain grate stoker, into which the fine coal which leaks through the grate drops, are so arranged that it is impossible to gather these drippings and return them immediately to the stoker, (as was done in the tests of boiler No. 10) the accumulation during a test was determined, and the weight subtracted from the coal fed to the stoker; the average amount of coal which so accumulated during these tests was 7.1% of that furnished to the stoker. Inasmuch, however, as this fine coal in its escapement from the grate always carried a little ash with it, this amount of 7.1% should have been 6.64%, therefore a further correction has been made for this reason, which gives an efficiency of 65.65% based on the coal fed to the

stoker, of which there was a loss, by weight, of 2.67% by carbon in the refuse; therefore efficiency based on coal burned, assuming no loss in refuse, is obtained by subtracting the sum of the total losses from 100, which is equivalent to 65.65 plus 2.67=68.32%.

In comparative tests of this character, it is desirable and necessary to secure a condition of combustion which will be the same in each case. The average CO_2 for the Fisk Street boilers being 9.52, the same should have been obtained in the tests of boiler No. 10. This boiler, however, was in a temporary setting and the walls were quite leaky, so that much air entered, and for this reason the CO_2 averaged 7.6 in test No. 2, which of the three was nearest to the Fisk Street condition; therefore in comparison of efficiency, test No. 2 has been taken as best representative of the improved boiler No. 10, and data therefrom are employed in the comparative heat balance. Table No. 1.

HEAT BALANCE FOR TESTS NOS. 1, 2 AND 3 OF BOILER NO. 10.

The following shows the distribution of heat actually occurring in these three tests:

ACTUAL DISTRIBUTION OF HEAT.

	Tests of Boiler No. 10		
Percentage of Heat	1	2	3
Usefully employed in making steam............	62.48	60.26	66.07
Lost in hot gases..........................	24.34	22.00	25.99
Lost by carbon in refuse......................	11.91	16.26	7.02
Loss by radiation and unaccounted for.........	1.27	1.48	0.92
Total	100.00	100.00	100.00

DATA FOR HORSEPOWER CAPACITY, 27 TESTS.

The horsepower value for the Fisk Street boilers of 812.3 is an average of twenty-seven tests made on the following dates: Dec. 24th, 1906, and in 1907—Jan. 4th, 12th and 22d, Feb. 26th, March 15th, 19th, 20th, 22d, 23d, 26th, 27th, 28th, 29th, 30th, April 3d, 9th, 10th and 24th, May 6th and 29th, June 4th, 11th, 13th, 14th, 15th and 24th. This figure of 812.3 has been considered the representative average horsepower value for the boilers in this station which are served by the chimneys 250 feet high. A lower horsepower value being recognized for those served by chimneys 200 feet high. In the comparisons, however, only the performance of boilers served by these high chimneys is considered. This accepted horsepower value is rather high than low, inasmuch as some large capacities, such as one test of over 1100 and three others of over 1000 horsepower were produced by a superior grade of coal from Southern Illinois which does not regularly get into the Chicago market.

The test on the improved boiler No. 10 used in comparison with Fisk Street is No. 3, which gave 624.5 horsepower. This is taken as representative for that boiler rather than the average of the three tests, for the reason that the horsepower value used for the Fisk Street boilers is an especially favorable one; therefore test No. 3 is more applicable to the comparison than either that of test No. 2, or an average of the three.

The average work performed in the superheater of the Fisk Street boilers is 8.05%, therefore the horsepower rating of 500 which is based on heating surface corrected as follows $(100\times8.05)\div91.95=8.75$, as the percentage of work in the superheater to that in the boiler. Thus, $500\times1.0875=543.7$ as the correct rating.

Diagram Fig. 6 shows the relation between draft and horspower output for these large boilers. If the draft prevailing in tests of boiler No. 10 is located on this curve, it will be observed that the corresponding developed capacity for the large boilers is less than that secured by the smaller No. 10, showing that the Fisk Street boiler although 36 per cent larger would produce less capacity than the smaller one.

LOSS IN HOT GASES.

The following tabulation will afford data bearing on this feature of the matter:

	Improved Boiler No. 10.	Babcock & Wilcox Boilers at Fisk St. Station.
Temperature of escaping gases	525.50	570.60
Percent CO_2 in flue gases	7.60	9.52
Heating surface required per horsepower developed sq. ft.	6.40	6.69
Steam pressure	125.30	180.00
Temperature of steam, Deg. F.	352.80	379.50
Excess in steam temperature, Deg. F.		26.70
Excess temperature in escaping gases, Deg. F.		45.10

from which it appears that boiler No. 10 had the advantage of lower steam temperature, which fact, of course, did have an influence on the final temperature of the gases. Inasmuch, however, as the excess temperature in gases is much greater than that between the steam in the two cases, it shows conclusively that the cooling capacity of the large boiler is inferior to that of No. 10, especially when the fact is considered that the CO_2 for boiler No. 10 is much lower than that which prevailed with the other, which influence, of course, is much greater than that due to difference in steam temperature; therefore in calculating the loss in hot gases in Table No. 1 for boiler No. 10, the final temperature is taken as 525.5, the average in test No. 2, and the loss for Fisk Street boilers, is based on a final temperature of 570.6, with 9.52% CO_2. The calculations are both based upon a coal composition represented by that in the first section of the appendix.

CARBON LOSS IN REFUSE.

This loss for Fisk Street Station was determined by collecting samples of refuse which were analyzed as was the coal which produced the refuse, and the amount of heat loss was determined by comparing the heat represented in the carbon in the refuse to the total supplied to the stoker during the period, and tests were made by sampling refuse from the entire station, there being some thirteen experiments in all. The analysis based on the sample from the entire station showed a heat loss by carbon in refuse of 1.94%, which seems to be representative of regular working conditions. Those tests, however, which were made on single boilers, wherein attention was given to the apparatus during the entire period of experiment, the loss proved to be 2.67%, and this appears to be the representative value which should be used for the Fisk Street boilers, inasmuch as other data employed was produced under similar conditions. Therefore this figure was used in connection with the efficiency of 65.65, loss in hot gases of 19.96 and radiation of 1.48, the sum of which is 89.76%, leaving 10.24% of the heat not accounted for, or in other words, lost in smoke.

LOSS BY RADIATION AND UNACCOUNTED FOR.

In test No. 2 of improved boiler No. 10, the heat losses by radiation and that unaccounted for as obtained by difference, is 1.48%, and inasmuch as no separation of these losses was feasible, no attempt was made to do so, therefore this figure stands as representing these combined losses for boiler No. 10, which may be a little high for radiation alone. These losses for the Fisk Street boilers obtained in the same manner, or in other words, by difference, is 11.72%, and it is here necessary to make a separation between the two; therefore, assuming the radiation to be 1.48% for the Fisk Street boilers, the

same as that allotted to both radiation and unaccounted for, for boiler No. 10. leaves a difference of 10.24% lost in escaping hydrocarbons and smoke for the Fisk Street boilers.

LOSS OF HEAT IN STOKER WATER BACK.

The stoker water backs at Fisk Street are connected with the boilers, so that all heat which is absorbed by them is actually employed in making steam. In the case of boiler No. 10, however, the water back was detached from the boiler, being supplied from an independent source with discharge to a hot well, therefore for results to be comparable required that a correction be made for the water flowing through the water back, which was done by measuring its initial and final temperature and the rate at which it flowed, the result from one test being applied to tests Nos. 1, 2 and 3.

DETERMINATION OF HEATING VALUE IN COAL.

All B. t. u. values of coal used in this connection are based upon determinations with the Mahler calorimeter; therefore possess an unusual degree of accuracy.

WATER MEASUREMENTS.

All water measurements for the Fisk Street boilers were made by special Keystone hot water test meters furnished by the Pittsburg Meter Company and carefully calibrated. In the tests of boiler No. 10, however, the water was measured by a Keystone hot water meter and also in calibrated tanks. In addition, the meter was carefully calibrated before and after the tests and found to be accurate in each instance. In this connection the author wishes to say he has had much experience with this type of meter, and that when it is new and in good condition its accuracy may be depended upon; the only danger to be apprehended is from the instrument becoming worn in service, but if used intelligently, much greater reliance can be placed upon measurements therewith than when water is weighed or measured in tanks, because the responsible heads of the test at the start, and finish, may make observations for themselves, which is impossible where a record of a large number of tanks must be made. Thus a reading of the meter at start and finish which may be participated in by all interested parties, gives conclusive evidence.

DESCRIPTION OF BOILERS.

The Fisk Street boilers are the regular B. & W. pattern, 14 tubes high and 18 wide, fitted with a double loop superheater of 960 sq. ft. area, served by a chain grate stoker of 90 sq. ft. in area, which discharges gases from the fire from under a flat ignition arch 7 ft. long, from which the gases enter immediately among the tubes of the boiler above

The ashes and refuse discharge from the rear of the grate into an ash hopper in the basement, from which they find exit at the bottom to a bucket conveyor. The fine coal which drops through the front of the chain grate falls into a hopper located just below, from which it finds exit to the same bucket conveyor to be returned again to the coal bunkers. The chimneys serving these boilers are 250 feet high. The chain grate stokers are of a new type and are much more accurately constructed than those usually employed Every provision has been made to exclude leakage of air above the fire, and as the ash hoppers are closed there is no opportunity for air to find its way above the fire from this source.

Boiler No. 10 is in a temporary setting, made necessary by changes in the power plant of which it is a part. The brick work at the time of the test was quite leaky and admitted a considerable amount of air. This boiler is made up of headers long enough for 14 tubes in height. Inasmuch, however, as the second and third rows of tubes were left out, the boiler is really but 12 high by 16 wide, the tile furnace roof being carried by the lower row of tubes which

are 3.5 in. diameter, made so for the purpose of insuring a thicker neck in the tiles. All tubes above this lower row are of the usual 4 in. diameter. The area of the chain grate stoker is 72 sq. ft. and the chimney 130 ft. high.

The ash and refuse from the rear end of the stoker finds its way into a shallow pit which extends out some distance in front of the stoker, air leakage in a measure being prevented from reaching the back end of the grate by a swinging damper which makes a joint between the stoker frame and the bottom and sides of this pit, which damper is raised when the refuse is raked out; during the time of its removal, there was a drop of CO_2 in the flue gases and also in the amount of water evaporated.

Unofficial observations made by some of the staff assistants on the work, might indicate that such reduction in capacity would be sufficient to bring down the total horsepower as much as 6%. In compiling the results, howeevr, no account of this has been taken.

NOTES EXPLANATORY OF TABLE NO. 3.

As has been explained, the results of the Fisk Street performance as presented, were based on various values submitted to the author. The data for efficiency was from one group of 18 tests. Loss in refuse was determined by a special series of experiments. All other features of the performance were from another selected group of 27 tests mentioned in the appendix. The reason for the adoption of this compilation method was to enable different people who had adequate knowledge of, but various opinions concerning the matter, to contribute, so that the result would not be simply the conclusions of the author alone. The principal values from Mr. Chauvet's tests as given to the author are presented in the first column:—

	Values for Fisk St. Performance	
	As given.	As they would have been if based on tests with coal equiva. to that used in the tests of Boiler No. 10
Horsepower	812.3	742.3
CO_2, per cent	9.52	8.99
Temperature of escaping gases	570.60	577.4
Draft over fire	0.713	0.733
Per cent of work in superheater	8.05	9.56

However, this table as now presented, containing all of the values for the Fisk Street performance in the fifth column are an average of these 18 tests.

In the advance paper details were given for tests Nos. 1, 2 and 3 only, but in its present form this table contains not only details for Fisk Street performance, but also another test made on boiler No. 10 which appears in the table as Test No. 4. This additional test 4 has been included on account of its being made with Illinois coal, thus enabling conclusions for the improved boiler to be based on a larger number of tests. Mr. Chauvet's endorsement as to the accuracy of the improved boiler tests refers to the first three, the accuracy of the fourth being certified to by W. J. Greene, of the Cedar Rapids & Iowa City Railway & Light Co., under whose direction it was made and reported to the author of the paper. Slight changes have been made in some of the figures of tests Nos. 1, 2 and 3 as originally presented, due to an ultimate analysis of the refuse having been made, which, together with other features are explained in the following, identified by a number corresponding to the item:—

6. In establishing a correct horsepower rating for the Fisk Street boilers, the fact is taken into consideration that a square foot of heating surface in the superheater is not equivalent in heat receiving capacity to an equal amount of surface in the boiler, and a correction is made on this basis as follows:

Work done by Superheater........................ 9.56%
Work done by Boiler.............................. 90.44%

Increase for Superheater.......................... $\frac{9.56 \times 100}{90.44} = 10.57\%$

Thus $500 \times 1.1057 = 552.8$.

the proper horsepower rating for the combination of boiler and superheater having 6,160 sq. ft. This rating would vary according to the amount of work done by the superheater. For example, if the condition of combustion is very good, with a high CO_2 and high furnace temperature, a proportionately large amount of work will be done by the boiler, leaving less to be performed in the superheater. On the other hand, if the CO_2 and consequent initial temperature be low, the boiler will do a correspondingly lesser amount of work and the gases will necessarily reach the superheater at a higher temperature, and it will perform more work than under the other condition, therefore this figure for corrected rated horsepower is larger than originally presented in Table No. 2, because that figure was based on the average of 27 tests, while the present figure is based on the proper group of 18 tests.

30. In the original reports of the tests, the average hourly weight of coal fed to the stoker was given as 3736.2 pounds, which was obtained by weighing the quantity shoveled into the stoker hopper, and subtracting therefrom the weight of leakage through the grate. This weight is corrected as follows:

Leakage through grate as reported.................................. 7.42%
Correct leakage through grate on account of 4.34% ash in excess found in fine coal, by analysis.................................. 7.10%
Leakage that should not have been subtracted from amount of coal as fed 0.32%
Correct amount of coal fed per hour..............$3736.2 \times 1.0032 = 3748.1$ lbs.

52. The average size of coal has been designated in the reports of the U. S. Geological Survey as the average diameter, which is a more definite expression, and equivalent in a screen to the size of perforations which will allow one-half to go through and the other half to pass over. The various sizes in the preceding items 42 to 51 are based on the coal actually used on the stoker in the combustion process. As mentioned in the appendix, with the Fisk Street tests, all of the leakage through the chain grate stoker was accumulated in the regular fine coal hoppers provided for that purpose, weighed after the tests were finished and the weight subtracted from the original weight of that fed to the stoker hopper, thus a superior grade of coal was used by the stoker than that fed to the hopper, because this fine coal was not returned to the stoker, therefore items 46 to 52 for the Fisk Street coal are corrected from the original reports on this basis, by deducting from the quantity through the 0.25 screen of the original sizing test, 7.1 per cent of the fine coal, and recalculating the new sizes as given in items 46 to 51 of Table No. 3. The average diameter of coal as fed to the hopper was 0.4923 of an inch, but the size actually employed on the grate in the combustion process after deduction for this 7.1 per cent fine coal, was 0.5681 of an inch.

63. In the original determinations of loss by undeveloped heat in ash pit refuse, the percentage of ash and pure coal was determined by analysis, and the pure coal in the calculations was considered as carbon, but after the presentation of the paper an ultimate analysis of the refuse was made and the loss calculated upon a more exact basis. As presented, the original figures given for loss by combustible in the refuse were as follows:—

Boiler No. 10, Test No. 1..................................11.91 per cent
Boiler No. 10, Test No. 2..................................16.26 per cent
Boiler No. 10, Test No. 3.................................. 7.02 per cent
Fisk Street Boiler.. 2.67 per cent

79. No account has been taken of the fact that the horsepower for the Fisk Street boiler was developed with a better quality of coal than was

charged against it; as stated in other portions of this explanation of Table No. 3, and particularly referred to in the remarks concerning items 88 and 90.

86. The expression pure coal as gasified requires some explanation. It is the equivalent of coal "burned." In a case of this kind, however, where it is the object to show that the process of combustion is not complete, it is manifestly out of place to use the word burned, as with the Fisk Street performance the coal was not completely burned but all changed to gas; therefore it is more definite and accurate to use the term gasified, because it accurately applies to the conditions in both cases.

87 and 89. These items for Fisk Street show the measure of efficiency for this boiler according to the original report as slightly corrected for in item 30, and represents the efficiency obtained with a better grade of coal than was charged against the boiler due to 7.10 per cent falling through the stoker to the fine coal hopper without being used in the combustion process.

88 and 90. These items show what the efficiency would have been, if the fine coal which dropped through the stoker into the fine coal hoppers had been returned to the stoker and used in the combustion process, as was done in the tests of the improved boiler. These values were obtained by reducing the reported efficiencies in the same ratio as those corresponding to the average diameter of coal fed and coal used (0.4923 and 0.5681) as shown in Journal Western Society of Engineers, Vol. XI, p. 537, Fig. 5. The efficiencies of this diagram corresponding to the average sizes of the Fisk Street tests are as follows:—

	Efficiency.
For average size 0.4923	58.9%
For average size 0.5681	61.4%
Efficiency ratio	0.9593

DISCUSSION.

President Abbott: The steam users of this country during the present year will have paid about $1,000,000,000 for fuel used upon the grates under their boilers. Of the enormous quantity represented by this sum, it is safe to say that half is wasted. Under favorable conditions it might be possible to save half of this waste and although general operating conditions are not always favorable, it is not improbable that with improved apparatus and greater intelligence in its manipulation at least one quarter of this waste, or $125,000,000 worth of fuel per year might have been saved. In the interest, therefore, of preventing this great waste which is going on, thereby saving posterity their share of the heritage of the wealth which yet is stored up in the coal seams, the discussion of ways and means of improving boiler efficiency is a live and intensely practical subject, and it is hoped that the presentation of this paper, and of others of the same kind, will create an interest in this important matter which will help us to improve the efficiency of our steam plants so that we may realize the great saving which we all know is possible.

Mr. H. Boyd Brydon, (with Sargent & Lundy, Chicago): I have listened to this paper with much interest, and possibly some of us have listened to it with not a little confusion of mind. I have been at considerable loss to ascertain, either from the paper itself or from Mr. Bement's corrections and amendations, just exactly how this efficiency of 80.18 per cent. was obtained. In the A. S. M. E. code

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TABLE No. 3.

RESULTS OF FOUR TESTS ON IMPROVED BOILER NO. 10 AND AVERAGE OF 18 TESTS ON FISK STREET BOILERS.

1.	Test number	1	2	3	4	Fisk St.
2.	Date of test, 1907	7/24	7/25	7/28	11/20	3/15 to 6/25
3.	Duration of test, hours and minutes	10:0	10:0	4:1	8:0	4:21
4.	Total heating surface in sq. ft	4,000	4,000	4,000	4,000	6,160
5.	Maker's rated horsepower	400	400	400	400	500
6.	Correct horsepower rating	400	400	400	400	552.8
7.	Grate surface in sq. ft.	72	72	72	72	90
8.	Height of chimney in feet	130	130	130	130	250
9.	Thickness of fire, in inches	6.600	6.625	5.875	8.125	7.736
10.	Steam, average lbs. gauge pressure	122.6	125.3	127.3	132.8	185.5
11.	Draft, average at fire in inches of water	0.214	0.262	0.203	0.270	0.733
12.	Draft, average at base of chimney in inches of water		0.650	0.725		1.550
13.	Temperature in boiler room, deg. F.	85	85	80	55	79
	COMBUSTION GASES.					
14.	CO_2 average per cent.	6.96	7.60	6.92	9.66	8.99
15.	Flue temperature, average deg. F.	537.8	525.5	562.8	546.0	577.4
	Heat Loss in Moist Gases, per cent., due to					
16.	Moisture in coal	1.68	1.76	1.46	1.82	1.39
17.	Burning available hydrogen	2.99	2.93	3.08	3.62	3.16
18.	Water of combination found	1.28	1.28	1.33	1.26	1.36
	Heat Loss in Dry Gases, per cent., due to					
19.	Carbon dioxide	1.62	1.50	1.86	1.94	2.06
20.	Sulphur dioxide	0.04	0.04	0.05	0.03	0.05
21.	Nitrogen	13.73	11.63	15.83	11.80	13.53
22.	Oxygen	2.24	1.77	2.60	1.44	1.82
23.	Total heat loss in hot gases, per cent., excluding hydrocarbons	23.58	20.91	26.21	21.91	23.37
	STOKER WATER BACK.					
24.	Total pounds of water passing through water back	108,000	108,000	43,380	83,330	
25.	Average temperature of water entering, deg. F.	79	79	79	45	
26.	Average temperature of water leaving, deg. F.	108	108	108	74	
27.	Total b. t. u. carried away by water	3,132,000	3,132,000	1,258,020	2,416,572	
28.	Heat loss in water back, per cent	0.99	0.94	0.99	1.00	
	COAL.					
29.	Total pounds of moist coal fed	29,600	32,200	12,003	22,800	16,304.2
30.	Per hour, average moist pounds fed	2,960.0	3,220.0	2,988.3	2,850.0	3,748.1
31.	Per hour, average dry pounds fed	2,537.9	2,749.5	2,624.0	2,421.3	3,332.8
32.	Per hour, average pure pounds fed	2,197.0	2,345.6	2,221.5	2,109.5	2,721.1
33.	Per hour, average pure pounds burned	1,939.1	1,972.6	2,069.0	1,985.6	2,655.4
	Analysis of Moist Coal.					
34.	Moisture	14.26	14.61	12.19	15.04	11.08
35.	Ash	11.51	12.54	13.47	10.94	16.32
36.	Carbon	55.57	54.54	55.65	56.57	54.35
37.	Hydrogen, available	2.92	2.85	2.91	3.37	2.85
38.	Sulphur, less S. in ash	3.60	3.54	3.61	2.46	3.53
39.	Nitrogen	0.91	0.90	0.92	1.04	0.89
40.	Water of combination	11.23	11.02	11.25	10.58	10.98
41.	B.t.u.	10,606	10,332	10,538	10,599	10,164
	Test of Size in Screens Having Round Perforations, Percentages, as Used on Grate. OVER — THROUGH					
42.	— 1/32	4.52	4.20	5.50		
43.	1/32 — 1/16	4.27	3.22	3.63		
44.	1/16 — 3/32	3.20	2.70	2.76		
45.	3/32 — 1/8	2.20	2.23	2.76		
46.	1/8 — 1/4	11.67	11.12	12.22		33.30
47.	1/4 — 3/8	8.70	10.50	8.52		13.72
48.	3/8 — 1/2	9.85	10.45	6.54		10.94
49.	1/2 — 3/4	17.60	20.82	17.20		16.76
50.	3/4 — 1 1/4	27.60	25.74	30.05		16.57
51.	1 1/4 —	10.39	9.02	10.82		8.71
52.	Average diameter as used on grate	0.9088	0.8840	0.9846		0.5681
	REFUSE.					
53.	Total pounds discharged into ashpit during test	5,594.6	6,877.1	2,060.6	2,880.0	2,606.9
54.	Average pounds discharged into ashpit per hour	559.4	687.7	513.0	360.0	599.3
55.	Average pounds of pure coal lost in refuse per hour	257.9	373.0	152.5	123.9	65.7
	Analysis.					
56.	Ash	53.89	45.76	70.27	65.57	89.03
57.	Carbon	41.08	48.33	26.49	30.68	9.25
58.	Hydrogen, available	0.56	0.66	0.36	0.42	0.27
59.	Sulphur, less S. in ash	2.22	2.61	1.43	1.65	0.54
60.	Nitrogen	0.57	0.67	0.37	0.43	0.11
61.	Water of combination	1.68	1.97	1.08	1.25	0.80
62.	B. t. u. per pound of refuse	6,395	7,522	4,123	4,775	1,530
63.	Heat loss in refuse, per cent.	11.40	15.58	6.71	5.68	2.41
	WATER AND TOTAL EVAPORATION.					
64.	Total pounds as fed	170,830.0	177,119.8	73,174.6	151,330.0	90,217.3
65.	Temperature as fed, deg. F.	91.10	106.95	96.50	149.30	135.70
66.	Factor of evaporation	1.1702	1.1540	1.1650	1.1113	1.1167
67.	Total equivalent pounds evaporated from and at 212 deg. F. including water back and superheat	203,148.4	207,639.4	86,551.1	170,675.4	111,400.9
68.	Per hour, average equivalent lbs. evaporated from and at 212 deg. F., including water back and superheat	20,314.8	20,763.9	21,548.0	21,334.4	25,609.4
	SUPERHEAT.					
69.	Square feet of superheater					960
70.	Horsepower developed in superheater					71.0
71.	Sq. ft. of heating surface required per horsepower developed in superheater					13.52
72.	Correct horsepower rating of the superheater on a basis equivalent to that of 10 sq. ft. for the boiler					52.8
73.	Temperature of steam					584.6
74.	Degree of superheat					202.8
75.	Specific heat of superheated steam					0.5035
	HORSEPOWER.					
76.	Correct rated horsepower	400	400	400	400	552.8
77.	Horsepower developed in boiler	588.8	601.8	624.5	618.4	671.3
78.	Horsepower developed in superheater					71.0
79.	Total horsepower developed	588.8	601.8	624.5	618.4	742.3
80.	Percentage developed to that of rated horsepower	147.2	150.4	156.1	154.6	134.2
81.	Square feet of actual heating surface per horsepower developed	6.79	6.64	6.40	6.46	8.29
82.	Square feet of heating surface per horsepower developed on basis of correct horsepower rating	6.79	6.64	6.40	6.46	7.44
	EVAPORATION AS REPORTED IN LBS. FROM AND AT 212 DEG. F. PER POUND OF					
83.	Moist coal fed	6.863	6.448	7.210	7.485	6.832
84.	Dry coal fed	8.004	7.552	8.212	8.811	7.683
85.	Pure coal fed	9.246	8.852	9.699	10.114	9.411
86.	Pure coal burned, (gasified)	10.475	10.526	10.414	10.744	9.644
	EFFICIENCY.					
87.	As reported, based on coal fed	62.48	60.26	66.07	68.20	64.91
88.	Correct efficiency based on size of coal actually used	62.48	60.26	66.07	68.20	62.27
89.	As reported, based on coal burned, (gasified)	70.78	71.66	70.94	72.45	66.52
90.	Correct efficiency based on size of coal actually burned, (gasified)	70.78	71.66	70.94	72.45	63.81

for testing boilers, there is a method given by which the efficiency of a boiler, based on combustible, may be ascertained. In the paper, as printed, and in the author's introductory statement tonight, there seem to be several corrections, deductions, additions and subtractions for ascertaining what the losses or gains might be, if something else that was not there, was there, and consequently I thought the best way about talking about something I did not understand would be to go back to the combustible basis, data for which were given in the results of the tests at the end of the appendix.

On figuring these boiler tests on the combustible basis, taking analysis of the coal, as given, for the ash and moisture, and crediting the boiler with the heat put into the water back, the efficiency based on combustible burned is as follows for the three tests reported:

Test No. 1—72.03 per cent.
Test No. 2—67.88 per cent.
Test No. 3—69.56 per cent.

Giving an average for the three tests, of 69.82 per cent, instead of 80.18 per cent. For this reason I, for one, simply cannot accept this figure of 80.18 per cent,: it was not obtained, and I doubt that it is even remotely possible to obtain it with the coal and boiler setting, as described.

The diagram of draft over fire interested me quite a little, because it brings into the discussion of boiler tests an entirely wrong method of ascertaining what you are doing or likely to do. The draft is given us at the uptake from the boiler. We can load that boiler setting full of brick, or we can take the brick all out and let the gases shoot up and we will get entirely different drafts over the fire, but the available draft we get in doing the work is the draft in the uptake, and any method of figuring the boiler test from a basis of draft over fire, is distinctly erroneous. As an illustration of the fallacy, may I give an example: I have, during the past few weeks, made a number of tests on a boiler of similar type and with the same coal. Now, in one of these tests the draft over the fire was 0.72 in., with a horse power of 560; in the other, draft over fire, was 0.53 in., but the horsepower, with the lower draft over the fire, instead of being much less, as the curve would suggest, was actually very much larger.

This is a sort of thing one encounters when one tries to compare boiler capacities on the basis of draft over the fire.

Another thing in regard to this somewhat remarkable curve: As I gather from the author's comments on his paper, he claimed this drop in horse power with increased draft is correct on the ground that if you get the draft big enough you will not be able to burn any coal; you will pull the fire away from the front of the grate. We know that if you get the fire away from the front you will have a hard time to get it back, but the whole point of this falling off of horse power seems to be, not the amount of draft, but that the draft might be out of proportion to the fuel bed, which the draft over the

fire really measures. It is roughly proportional to the resistance of the fuel bed. If you take a good coal, free from duff, and running about ¾ inch, you will have a comparatively small draft over the fire. If you have a lot of duff in the coal, you will have a big draft over the fire; but this curve ignores this, and simply shows that if you increase the draft to about 1.3 in., you do not get any horse power. I would like the author to explain what happens if the draft over the fire be increased to, say 1.5 or 1.7 in. Do you get some new form of refrigerating machine?

It is unfortunate, it seems to me, that the author has not stuck to his test. The paper states that "the test on the improved boiler No. 10, used in comparison with Fisk Street, is No. 3, which gave 624.5 horse power. This is taken as representative for that boiler," etc.

He pins his faith to test No. 3, apparently, because it gave the best horse power, but as it does not give him several other good things, he takes these from another test. Thus, under the heading "Loss in hot gases" the flue temperature quoted (525.50°F.) is from test No. 2. During test No. 3 this averaged 562.8°F. (See Appendix). The CO_2, 7.60 per cent., is also taken from test No. 2. On test No. 3 the CO_2 was 6.92 per cent. The horse power developed on test No. 2 was 601.8 instead of 624.5. This is not a convincing method of figuring. If a clerk in a bank has a deficiency in one's man's account and makes it good from another account, he runs a great chance of being charged with embezzlement. A much similar law applies in scientific work. There is no possible way that I can see where a man has any right at all to take part of his data from one test and part from another, and a little guess-work, and offer the result as a statement of something actually obtained or obtainable. Certainly it is not safe engineering.

I do not think it worth while to refer to the comparison made with certain tests at Fisk Street Station, except to prevent a possible misconception regarding them. The interest taken in these now almost classic twenty-seven tests must be a source of gratification, not to say amusement, to the engineers of that station. The author is misinformed as to the object of these tests. They were not boiler tests, in the strict sense of the term. They were simply coal tests—routine tests made under ordinary operating conditions, to ascertain approximately the relative value of various coals—good, bad and indifferent, for steam raising purposes. The object of the test was not, as might be supposed from the fame they have achieved, the establishing of any special records in boiler operation, but to find the coals which gave the lowest cost of evaporating 1000 pounds of water.

Sufficient data to construct a heat balance was not taken during the tests; consequently the heat balance given by the author in Table No. 1 should be accepted only as his guess at the probable conditions. The figure for radiation loss is probably too low, and the statement that the unaccounted for loss is smoke, is bare assertion.

Professor Breckenridge in a recent Bulletin (No. 15) of the University of Illinois, well says "Smokelessness is a relatively safe indication that the total heat has been liberated. Unfortunately it gives no indication of the degree of efficiency with which the heat is being utilized."

The author is to be congratulated upon the sample of 1.25 in. Pawnee screenings he was able to obtain for these tests, at Cedar Rapids. The proportion of coal of desirable size for stoker use contained in it was considerably above the average.

Just a few words as to the tile roof, itself. The tile roof is not new. The application to a Babcock & Wilcox boiler is not new. It was at least twenty years old when applied to the Heine boilers at Harrison Street Station of the Commonwealth Edison Company. It was not applied to those boilers with the idea of stopping smoke but in the hope that it might prevent tube troubles. In this it was successful.

Mr. F. Chauvet, (Fuel Engineer Fisk St. Station, Commonwealth Edison Co., Chicago): My purpose in coming to this meeting was rather to gain than impart information. I am, however, ready to respond to the President's request for a discussion of the paper which has been presened to us.

I was present at both the Fisk Street and Cedar Rapids tests referred to by the author, therefore familiar with the conditions of both. In the field of boiler testing as in other lines of work, two classes of persons are recognized, experts and those who are not experts, the difference being that an expert is allowed by virtue of his mastery of the subject in arriving at conclusions to assume what he believes, whereas the other class, to which I belong, is limited to actualities and must restrict itself to what is weighed, measured and determined experimentally, and calculated from such actual data. If I make comparisons, it will be on conditions existing when tests referred to were made.

No objection is made to the basic data obtained on the actual tests as set forth in the author's paper, nor is the technique of the calculations criticised. However, I do strongly question the author's right to use assumed conditions and values never realized in actual tests, and then to draw deductions and make comparisons from calculations based thereon, for the following reasons:

1st. Quantities are not all actualities.

2nd. No account is taken of relative changes in other factors in changing the CO_2 from 7.6% to 9.6%.

3rd. Conditions realized at Fisk Street with supposedly inferior setting are embodied in the Cedar Rapids heat balance to prove that this Cedar Rapids furnace is superior to those at Fisk Street.

Therefore I have considered the eight elements entering into the matter in the following numbered paragraphs:

1. 812 Horsepower is a favorable one the author states, for the Fisk Street boilers. In looking over past records this appears an

ordinary and not the maximum performance, yet in his comparison he has taken for the Cedar Rapids boilers the test giving the maximum capacity.

2. Regarding draft, Fig. 6 is the basis for the author's comparisons of horsepower capacities. This chart is from the group of 27 tests mentioned in the appendix and made at Fisk Street, the points representing draft over the fire, yet with the same strength of draft over the fire horsepower has ranged from 600 to 1100. It does not follow that the amount of coal burned or the horsepower developed are relative to draft over fire, because this draft is but a measure of the resistance offered by the fuel bed to the air, and this resistance increases or decreases according to size of coal, thickness of fuel bed and fusible constituents in the ash. For these reasons the stack

TABLE No. 4.

PAWNEE 1-1/4 INCH SCREENINGS.

	Fisk Street.	Cedar Rapids.
Test Nos.	19 21 23 24	1 2 3
Efficiency (73)	65.9 64.5 66.4 65.2	62.48 60.26 66.07
Average Efficiency	65.5	62.94
Horsepower Developed	806.4 803.6 767.6 814.4	588.80 601.80 624.50
Average Horsepower	798.0	605.00
Capacity, percent of builder's rating	159.6	151.25
Analysis of Coal as Fired:		
Moisture	12.34	13.69
Ash	14.72	12.51
B.t.u.	10,408	10,492

draft should be used as a basis of comparison for capacity. The chart shown is a typical shot gun pattern with 80% of the points falling inside of a ¾ in. circle. The last part of the curve has no points to determine its direction, and, if we follow it until the draft becomes 1.3 in. zero horsepower is reached, thus at 1.5 in. draft, the boiler would give a negative horsepower of 400. As a matter of fact, if draft was from 1.3 in. to 1.5 in. over the fire, the fuel bed could be proportionally thickened and thus avoid the drop indicated by the last part of the author's curve.

3. The CO_2 value of 9.52% is another objectionable feature which the author has employed in his comparative heat balance. It was not obtained at Cedar Rapids, therefore its use is an unwarranted assumption, because with 56% combustible in the refuse it was pos-

sible to obtain only 7.6%, and if the fire had completely burned out, as good operation requires, it would have been only one half as thick and air leakage would have been very much more, so that instead of there being a possibility of 9.52% CO_2, it would have been even lower than the 7.6% actually obtained. Comparison of tests Nos. 2 and 3 bears this out, as in No. 3 there was much less conbustible in refuse and with a thinner fire the CO_2 was lower, although combined efficiency was much higher.

4. No account has been taken of change in temperature of flue gas which would have been caused by different CO_2.

5. As showing relative efficiency, I have prepared Table 4 for Pawnee coals for both outfits, and Table 5 of Iowa coals at Cedar Rapids compared to Fulton Co., Ill., coal used at Fisk Street. How close these coals are in heat value and ash, can be seen from the analysis accompanying the tabulation. The Fisk Street performances were from ordinary coal tests without elaborate effort for high re-

TABLE No. 5.

FULTON COUNTY ILLINOIS, AND IOWA SCREENINGS.

	Fisk Street Fulton County 1-¼ Inch Screenings.	Cedar Rapids Iowa Screenings.
Test Nos.	49 52 53 54 55	4 5
Efficiency (73)	64.24 66.20 63.20 66.50 64.50	58.27 52.28
Average Efficiency	64.20	55.27
Horsepower Developed	667.00 752.00 756.00 759.00 742.00	502.30 467.00
Average Horsepower	735.20	484.60
Capacity, percent of Builder's Rating	147.00	121.15
Analysis of Coal as Fired:		
Moisture	12.10	11.90
Ash	20.40	19.20
[illegible]	9,432	9,853

s and represent ordinary operating conditions. Referring to the s on Fulton Co. coal at Fisk Street which was as poor as the Iowa used at Cedar Rapids, Fisk Street conditions were the same as e of the Cedar Rapids boiler when using Iowa coals, yet, according to the author, the tile roof is of particular benefit when burning e poor coals. The comparison of the performances of the two

boilers in Table 5 will show the superiority of the Fisk Street results with the dirty coal.

6. The author makes the plea that it was necessary in the Cedar Rapids tests to run large amounts of coal into the ash pit in order to prevent serious air leakage at the back of grate. There were, however, two dampers at rear end of the grate to exclude air; also one in the ash pit and an intermediate damper between the grates. It is well known that one of the serious faults of a chain grate is the serious air leakage at the rear, due to the tapering fuel bed, and that CO_2 can easily be increased by banking the fire at the rear end. But this can be done only at the expense of large losses of unburned coal falling into the ash pit, and it is desirable to obtain the best possible CO_2 with the least loss into the ash pit, because the gain from raising of CO_2 a few per cent can be squandered several times over by the enormous losses due to unburned coal. This was the state of affairs in the Cedar Rapids tests as indicated by the refuse analysis. Fisk Street

TABLE No. 6.

EFFECT OF SIZE OF COAL ON CAPACITY AND EFFICIENCY.

	Size of Coal, Square Screens.				
	1-inch	¾-inch	½-inch	¼-inch	Duff through ¼-inch
Pounds of coal burned per hour	2625	3825	3900	3197	1425
Pounds of coal burned per sq. ft. grate, per hour	35.0	51.0	52.0	42.6	19.0
Equivalent lbs. water evaporated per lb. of coal as fired	6.69	7.40	7.61	6.49	2.58
Efficiency based on coal as fired	61.74	67.54	70.71	65.26	26.43
Horsepower Developed	510.0	820.0	860.0	601.8	106.60
CO_2, percent	6.6	7.8	8.0	6.3	1.60
Efficiency, relative values	87.31	95.51	100.0	92.29	37.38
Capacity, relative values	59.30	95.35	100.0	69.98	12.32
Analysis of Coal as Fired:					
Moisture	11.40	11.40	10.10	10.40	10.70
Ash	12.20	12.40	13.88	18.51	27.45
B.t.u.	10,467	10,583	10,395	9,606	9,430

burned 97.3% of its coal, 2.7% going in ash pit. Cedar Rapids burned but 83.7% of its coal, 16.3% going in ash pit. If Fisk Street had burned but 83.7% of its coal by banking fire in the rear, the CO_2 would have increased considerably over 9.6%. If the Cedar Rapids boiler had burned its coal as thoroughly as those at Fisk Street, the fire would have been thin in the rear and the CO_2 very much lower than 7.6% obtained with the fire banked against bridge wall. Under such conditions if heat balances are made, it is manifestly unfair to the furnace burning all but 2.7% of its coal as compared to the one having its fire banked in the rear, for the purpose of securing a false CO_2 thereby, for the author to credit each furnace with the coal wasted, because the Cedar Rapids boiler was credited with 16.3%—2.7% or 13.6% more than Fisk Street, which is taking boiler testing beyond the scope of experimentation. This is depreciating good, and

putting a premium on very poor operation. A fireman running his fires in this manner would soon be looking for another position.

7. Heat lost by radiation and unaccounted for, according to the author's figures, are unreasonably small. In the work of the U. S. Geological Survey, radiation was found to be from 3 to 5% according to capacity developed, yet Mr. Bement considers it only 1.48 for both radiation and unaccounted for. With a radiation equal to that of the U. S. Geological Survey tests, he would have a minus quantity for unaccounted for. This would mean perfect combustion and 100% efficiency for the tile roof. Still more, it would mean perfect combustion at all capacities for high as well as low CO_2. But referring again to the work of the U. S. Geological Survey since its results are readily available, on page 24, chart No. 12 is shown that this is not true, because as the CO_2 increases, there is a drop in the furnace efficiency due to a less perfect combustion. This is found on a Heine boiler with a tile roof and a combustion chamber adequate for the slight variations of careful hand firing. It is also of interest to compare Mr. Bement's unaccounted for losses with the same item on the U. S. Geological tests, as both these boilers are equipped with tile roofs.

U. S. GELOGICAL TESTS.

Six tests on Illinois coal	8.33%	unaccounted for
Three tests on Indiana coal	9.51%	unaccounted for
Six tests on Iowa coal	10.68%	unaccounted for

making an average of 9.5% for the above fifteen tests and according to the author's figures, the Fisk Street unaccounted for is 10.24, practically no difference for tile roof and no tile roof. Yet at Cedar Rapids, Mr. Bement found but 1.48% unaccounted for. Now why there should be such an extraordinary difference is not explained by hand firing against stoker firing, because the U. S. Geological tests had the benefit of very careful hand firing, also a large combustion chamber with special mixing device in it. Furthermore, since the Cedar Rapids tests, very carefully conducted ones on a chain grate stoker with the same type of boiler, using a tile roof, showed a persistent 8 to 10% unaccounted for. This was found also when the flames had absolutely disappeared before reaching the tubes in the first pass, whereas in Mr. Bement's tests the flames extended well up through the first pass giving visual evidence of an inadequate combustion chamber for capacity run. However, according to Mr. Bement, his results are some 8 to 9% better than other tile roof outfits.

8. There was a large advantage due to superiority in size of coal used in the Cedar Rapids tests, and this fact should have been taken into consideration, the per cent of duff being only 25.4%. At Fisk Street the percentage of duff in coal used was 39.93%, and making allowance for fine coal which fell through the grates at Fisk Street, the coal used at Cedar Rapids still contained 7.5% less duff. The effect of this on both capacity and efficiency is shown by Table 6,

which is from tests made by me under Mr. Bement's direction at Fisk Street Station for Mr. Abbott.*

Prof. L. P. Breckenridge, M.W.S.E.: The boiler and furnace described by Mr. Bement appear to the writer to be in accord with good present design for burning highly volatile bituminous coal with economy and without smoke, and we are glad to have the results of tests made with this combination presented to the Society.

The writer's experience with hot water meters for boiler testing does not exactly coincide with that of Mr. Bement; in fact, we have tried on several occasions to justify the use of water meters in this connection but the results have always been disappointing. We have made at different times numerous attempts to determine radiation losses from boiler settings, and the results have not been satisfactory. In no case, however, have the results ever indicated radiation losses lower than 2 per cent., and it is our opinion that radiation losses seldom are less than 3 per cent.

Upon first reading this paper the writer's ideas as to possible boiler efficiencies were somewhat disturbed, the results given from the tests in Table No. 1, are so at variance with results of tests with similar sized fuels and with equally smokeless furnaces. With ½ in. screenings of which 30 to 40 per cent passed through a ¼ in. sieve, we have succeeded at the Engineering Experiment Station in obtaining under most favorable conditions to the fuel, i. e., 6 inch depth of fuel bed at the gate, and 0.26 in. draft, a combustion giving 7% CO_2 in the flue gases and a resulting efficiency for the "boiler and furnace" of 59.14. The per cent of ash in moist coal was 17.42. The per cent loss of heat to stack corresponding to a mean value of 7% CO_2 is 25.05. (This is an engineering experiment station test No. 91a.)

Comparison of these data and the results given in Table 1 of the author's paper leads to a recalculation of values from the data given for test No. 2, Table No. 3. The computation of the heat balance necessitated the calculation of the analysis of the coal to a wet coal basis which is as follows:

	"Pure Coal"		Moist Coal as fired.
Carbon	74.86		54.53
Hydrogen, Available	3.92		2.86
Sulphur	4.86	×(1.00—.2715)=	3.54
Nitrogen	1.23		.90
Water Combination	15.13		11.02
	100.00		
Ash	12.54		12.54
Moisture	14.61		14.61
			100.00

*Journal Western Society of Engineers, Vol. XI, p. 529.

The results of recalculating the heat balance are:

	Percent of heat in coal as fired	Percent corrected for Ash Pit Loss	
		Recal.	From above
Absorbed by boiler	60.26	71.66	80.18
Stack loss in dry gases	18.32	21.88	18.34
Loss due to moisture	3.08	3.68	
Loss due to burning available hydrogen	3.10	3.70	
Ash pit loss	16.26	0.00	0.00
Total	101.02	100.92	98.52
Radiation and Unaccounted for loss by difference		.....	1.48

The author has evidently obtained the value 80.18 by adding to 60.26 the sum of 16.26 and (22.00—18.34), which is not justfiable. The author uses this same manner of correction for the loss of carbon to ash pit for the Fisk Street boiler. It is remarkable that the results when correctly computed show no radiation and unaccounted for balance. It is usual in all tests which have come to the writer's notice and which have been computed in the ordinary manner, to find a deficit of from 4 to 10 per cent which is credited to radiation and "unaccounted for." From the experiment station tests which are to be published shortly, it has been found that this deficit for the chain grate from usual methods is about 7 per cent, which is considered extremely favorable, compared with 8 to 16 per cent as found with hand fired furnaces and often even with automatically stoked furnaces.

Mr. C. S. McGovney, Engineering Experiment Station, Urbana, Ill.: I have been greatly interested in the manner in which Mr. Bement has made a comparison of these two types of boilers. There would certainly be a rose strewn path for the tile roof furnace if it could burn up the unaccounted for loss. However, Professor Breckenridge has shown that the indications of such a phenomena are due to erroneous methods in the calculations.

I have nothing but commendation for the tile roof furnace applied to the Babcock & Wilcox and Heine types of boilers, and the author's method of fitting the B. & W. boiler with such a furnace seems to be the best solution in that connection which has been presented.

I have read Mr. Bement's paper with considerable care and it seems that there are some points essential to the value of the paper which should be brought out. I wish that the author might give some information on the following:

1. Has he made any investigation which shows that 10.24 per cent of the heat in the coal may be lost in smoke as stated.

2. What was the thickness of the fuel bed in the capacity tests shown in the curve, Fig. 6, and what size of coal does this curve represent?

3. Referring to Table 2, what was the average depth of opening of the feed gate for the Fisk St. Station boilers corresponding to the draft of 0.713 in. over the fire?

The point is this—The 210 horsepower Heine boiler at the University of Illinois, engineering experiment station, is supplied with a grate area of 38 sq. ft. which is 0.18 sq. ft. for one horsepower. The No. 10 boiler of this paper has 0.18 sq. ft. per horsepower, and the Fisk St. Station boilers have 0.18 sq. ft. per horsepower, excluding the superheater. Now with the character of fuel and size as indicated in this paper, it is found, that, with the experiment station's Heine furnace, the most economical draft pressure for a fuel bed of a depth given by a 6 in. gate opening is about 0.26 in. over the fire. If this amount is exceeded both capacity and efficiency drop off rapidly, due to the fuel bed becoming broken. Anything approaching the draft 0.71 in. would be disastrous. Perhaps Mr. Bement will explain this apparent inconsistency and correlate it with the assumptions which have been made in the last two items of Table 2 and with the statement made in the paragraph relating to the effect of the tile roof upon the rate of combustion.

Mr. Charles Bollinger, Chief Engineer Western Electric Co., Chicago: I am not prepared to offer any discussion of Mr. Bement's paper, except, perhaps, to say that I attempted to figure out the author's method of making his heat balance, and gave it up as a bad job. Mr. Pennock, however, who is present, can possibly say something.

Mr. G. A. Pennock, M.W.S.E.: I was glad to note that the figures I arrived at for efficiency check very closely with those of Professor Breckenridge. I deduced the heat balance based on coal burned (Table No. 1 in the paper) by dividing the items in Table No. 2 by (100—16.26) giving the following:

Usefully employed in making steam	71.51
Lost in hot gases	26.27
Loss from radiation and unaccounted for	2.22
	100.00

Another check on this figure of 71.51 may be obtained as follows from the data of test No. 2 in the appendix:

Total dry coal fired	27,495.
Per cent loss in ash	16.26
Dry coal burned	23,024.
Per cent loss from water back	0.94
Dry coal available for boiler	22,808.
B. t. u. per pound	12,100.
Total B. t. u. available	275,976,800.
Equivalent water evaporated	204,396.2
B. t. u. in steam	197,385,410.
Per cent heat absorbed by boiler	71.52

No correction is made for moisture in steam which doubtless amounts to one and one half or two per cent in a Babcock & Wilcox type of boiler when run at 50% above its rated capacity.

No mention is made in the heat balance of the loss due to moisture in the coal, hydrogen, or carbon monoxide. Assuming no monoxide the first two items amount to at least five per cent. If this amount be added to the heat balance the total would be over one hundred per cent so that it is manifestly incorrect to assume that the loss from radiation was 1.48 per cent.

Mr. Bement states that there was a loss of 2.67 per cent from carbon in the refuse, and that, therefore, the efficiency, based on coal burned, becomes 65.65 plus 2.67 equals 68.32. The correction should be made by dividing 65.65 by (100—2.67) which equals 67.45 instead of 68.32.

I should like to ask with what apparatus the flue gas analysis was made on test of No. 10 boiler and also what degree of accuracy may be expected from the Keystone Meter?

Prof. Wm. Kent, (Syracuse University, Syracuse, N. Y.): The setting shown in Fig. 1, appears to me to be admirable with one exception: the arch over the chain grate being carried into the furnace is apt to burn out. I should not expect it to last more than three months with semi-bituminous or Pittsburg coal containing not over two per cent of moisture. It is possible, however, with Western coals high in moisture it may last for a long time.

Table No. 1, does not seem to be referred to in the text of the paper, and it should be explained why this boiler No. 10, in the test in Table No. 1 showed 80.18 per cent efficiency and in the highest of the three tests in table No. 3 it shows 66.07%. I consider the figure 80.18% too good to be true with Western coal.

The heat balance, Table No. 1, allows nothing for loss due to evaporating and superheating the moisture in the coal, nor for the loss due to moisture in the air.

Mr. Bement states that the average CO_2 for the Fisk Street boiler was 9.52 and for the No. 10 boiler 7.6. Both of these figures are very low. We are getting from 12 to 16 per cent CO_2 in eastern tests.

It is interesting to note that whenever there is a low efficiency, the figure for "unaccounted for loss" is high. This has frequently been observed. It probably means that there is a large loss due to unburned hydrogen or hydrocarbons in the chimney gases which are not found in the ordinary analysis. With moist coal there should be a production of water gas in the furnace, due to the reaction $H_2O+C=2\,H+CO$. This would cause great loss of economy if the hydrogen of this water gas passed off unburned.

The diagram, Fig. 6, is interesting in showing that increasing the draft from 0.6 of an inch of water to over 1.0 in. does not increase the horse power. I have found a similar state of things occasionally with Western coals myself, and it was thus explained: Increasing the draft burns more coal for a short time, makes more ash, the ash runs into clinker and chokes the draft—so that with a higher pressure of draft we have an actually diminished air supply and dimin-

ished horsepower. This condition is not likely to happen, however, with Eastern coals, especially if shaking grates are used to keep the bed of fire free from ash.

Mr. C. H. McClure, Junior M.W.S.E., (Testing Dept., Commonwealth Edison Co., Chicago): The first thing in Mr. Bement's paper to which I would call attention is the title. The title is general; the subject specific, dealing only with the Standard Babcock & Wilcox boiler and its improvement due to change in the gas baffling and the application of the tile roof furnace. The improvement of the steam boiler, in general, is a very large and diverse problem and the improvement of the standard B. & W. boiler is a large section of this problem. Because of its durability, safety, and many other commendable features the standard B. & W. boiler has had much to draw the favorable attention of steam users. Recently, however, on account of the agitation against the smoke nuisance, it has accumulated more notoriety than fame; for it is a chronic smoke producer when fired with Illinois coal. It seems to me this title should more properly read, "Some Results Due to Improvement in the Standard Babcock & Wilcox Boiler and Furnace Design," for it is with the standard B. & W. apparatus and with its improvement that the author deals.

That the arrangement of gas baffling shown in Fig. 1 of Mr. Bement's paper will prevent smoke when the coal is fed to the fire in a uniformly regular manner, such as attained by the chain grate, is generally accepted as a fact. That this arrangement has no injurious effect upon the steam making qualities, but quite to the contrary, enhances the value of the apparatus as a steam producer, is very clearly shown by the results of tests which Mr. Bement presents.

Referring to Table 2: The items giving ratios of "horsepower and capacities developed per sq. ft. of heating surface with equal draft for both boilers," calls for some further explanation. The test boiler at Fisk Street Station is one of many discharging into one stack. Supposing, as an extreme case, that the test boiler grate were covered with a highly fusible ash, to a large extent prohibiting the passage of air through the grate, and that all of the other boilers were fed with a coal containing very much less ash which showed no tendency to clinker. It naturally follows that the draft of the stack would be high and that the draft over the fire in the test boiler would approximate the stack draft, which conditions would give a high draft with low capacity.

Again, in Fig. 6 in the appendix, the author presents a curve for which he has, in my opinion, very little authority. The first part of the curve, from zero to 0.6 in. draft might be taken as approximately correct, but even so, it does not seem to be established in any way by the points shown, excepting, perhaps, that the peak of the curve lies somewhere within the bunch of points, and the zero point would, of course, be located at the point shown. As a matter of abstract reasoning we might easily come to the conclusion that the

curve should continue to rise. As a matter of practical working this is not so. The projection of the curve downward, however, seems to call for further explanation.

The experiment with the model boiler is of considerable value, in that it confirms observations made in tests of more practical nature. I have carried out this experiment in a somewhat similar manner on a model much like that shown in the cut, but having a single tube instead of three. The circulation of the water was in the direction of the higher end of the tube and could only be reversed by heating the upright tube or water-leg connecting the lower end of the horizontal tube with the drum. This experiment seems to indicate that a reversal of circulation, even should it be found desirable would be difficult of accomplishment.

Mr. W. J. Greene, (Cedar Rapids & Iowa City Railway & Light Co.): When this boiler which Mr. Bement has described was installed for us, in addition to the fear that the circulation of the water would be reversed, many persons suggested other difficulties that would be encountered, namely: that explosive gases would collect in the first passage just under the drums and when mixed with air coming through the fire would explode, causing damage to brick work; that dust would collect in the open spaces between the first and second rows of tubes so rapidly as to seriously cut down the draft or cause much extra work to keep the dust removed; and that the bafflle walls could not be kept in place. None of these troubles have been encountered. The tests show that even if such gases could collect at the point claimed, no explosive gases are left. As to the dust, with the exception of a small accumulation at the front water legs and first bafflle, the passage is kept clear by the draft and requires no cleaning. The bafflle walls have given no trouble whatever.

The boiler has been in almost continuous operation since January 1, 1907, and is liked better and better by its operators and owners, as well as the local stationary engineers in our city.

Referring to the proposed setting shown in Fig. 5, I wish to emphasize a sixth objection. From the writers' experience, he would expect to see the radiation and unaccounted for losses to be increased from 1.48% to a quantity not far less than the amount of the unaccounted for loss for the standard Babcock & Wilcox boiler, and should this be true, there will be no advantage in this extremely high setting as far as efficiency is concerned, even if it be smokeless.

Regarding other objections to this high setting, it would seem that an allowance should also be made for increased cost of a wider as well as a higher building. A much wider passage should be had at the rear of the boiler to permit of cleaning tubes with economy in labor as compared with the setting shown in Fig. 1. Further, some means should be provided for taking care of the water used in cleaning and the resulting scale and dirt which would be discharged from the front headers, otherwise a bad mess will be made in front

of the boilers and the grates and the ignition arch would suffer damage, with consequent increased repairs and depreciation.

The writer would like to know what advantages are claimed for the setting shown in Fig. 5 over that in Fig. 1.

Mr. John B. C. Kershaw (The West Lancashire Laboratory, Waterloo, Liverpool, Eng.): I am greatly interested in the results set forth in Mr. Bement's paper. The idea of constructing an arched combustion chamber—below the tubes of a water-tube boiler is not new, but Mr. Bement has improved upon earlier designs, and is the first engineer to publish tests showing the superior efficiency of the modified furnace and setting. Mr. W. H. Booth and myself in our book on Smoke Prevention, published by Constable & Co. in 1904, have also advocated this form of construction for the furnaces of water-tube boilers, and have shown that such a combustion chamber is essential when burning bituminous fuel under this type of boiler. On page 56 of this book, a water-tube boiler setting, with a double arch above the grate, is shown and described,—while on page 153 of the same book the Miller form of furnace construction, for these boilers is described and illustrated. The latter construction is now in use in a large number of electricity supply stations in the United Kingdom,—and also at Messrs. Crompton's Engineering Works at Chelmsford. Although this method of construction has been adopted in many works in the United Kingdom, I am not aware that any comparative figures based on actual tests showing the superior efficiency of the improved setting have been published, and I am therefore greatly indebted to Mr. Bement for supplying this missing link in the chain of argument. Boiler-makers and users as a class seem to be singularly conservative in their views upon the design and working of steam-boilers. It is little to their credit, that years of effort and talking have been required, to convince them that any improvement upon the ordinary design of furnace for water-tube boilers is possible. The scientific principles of combustion have too often been absolutely ignored, in connection with this type of boiler, and fully one-half of the factory smoke produced at the present day, may be ascribed to the ignorance or prejudices of those who build and use this type of steam-boiler.

However, we may hope that such papers as those contributed by Mr. Bement to your Society, are slowly helping to break down this wall of conservatism, prejudice and ignorance and that in time the production of black smoke from factory boiler installations will have become a rare and striking phenomenon.

One omission there is in Mr. Bement's paper which I trust he will make good in his reply to the discussion and that is, the omission of any information as to the character and cost of the materials used, for building his brick arch, over the grate,—and the life of the same arch under normal conditions of work.

President Abbott: The amount as well as the kind of criticism which has greeted Mr. Bement's rather simple paper appears to be

out of all proportion to any statements therein contained, and would lead to the inference that he has touched upon an exceedingly live and tender subject.

I refer to the paper as a simple one because it is merely a comparison of the performances of two water tube boilers, one with a tile roof above the furnace and one without; and as my name has been mentioned in connection with the adaptation of such a tile roof to boilers and furnaces of this kind, it may not be out of place for me to contribute to the discussion.

There are many features which go to make up a boiler design, just as there are many conditions which contribute to the results of a boiler test, and in order to compare by a steaming test two boilers as regards certain features of their respective designs, it is essential that all other features and conditions be identical or else that a proper correction be applied to the results to allow for the effect of the points of dissimilarity.

Mr. Bement attempts to show the value of a tile roof above a furnace by making a comparison between the results obtained with a boiler having such a furnace and a similar boiler with an ordinary furnace, and if these two pieces of apparatus had been alike in all other features, the comparison would have been easy to make. Unfortunately, however, for the simplicity of the case, there were other points of dissimilarity, as follows:

	Standard Boiler	Improved Boiler
Draught,	Good	Poor
Setting,	Tight	Leaky
Combustible in refuse,	Little	Much

The right of Mr. Bement to apply some of the corrections which he did is questioned by his critics, and it now remains for the author to present such arguments in defense of his methods as he can, but aside from such comparisons as Mr. Bement has made, the conclusions from which are bound to be more or less questioned, I believe that we may at least approach the subject in a way not liable to criticism by ignoring the effect of the difference in draught and in the condition of the brick work and making a comparison of the performance of the two boilers on the basis of ratio between water evaporated and combustible burned.

For this purpose I have compared the average of the eighteen Fisk Street tests, which Mr. Bement cites, with the average of the three Cedar Rapids tests, as follows:

	Standard Boiler	Improved Boiler
Draft over fire	0.713 in.	0.226 in.
CO_2	9.52	7.16
Lbs. of combustible burned per square foot of grate per hour	29.43	27.69
Square feet of heating surface per B. H. P. developed	7.44	6.61

Lbs. water evaporated per hour per square foot of heating surface....	4.63	5.22
Lbs. water evaporated per lb. of combustible burned.............	9.67	10.47

From the foregoing it appears that, in spite of the handicap which the improved boiler had to contend with in the way of poor draft and of excess air through its faulty setting, it actually excells its rival both in the amount of water evaporated per square foot of heating surface and in the amount of water evaporated per pound of fuel burned.

It would be interesting to speculate upon the extent to which the difference between the performances of these two boilers would have been increased had all conditions been equally favorable, but in the absence of more definite information we may content ourselves with the assurance that from the showing already made the simple application of a tile roof of moderate length to a boiler furnace increases both the boiler efficiency and the boiler capacity, to say nothing of solving the annoying smoke problem.

Mr. Carl Scholz, (Chicago, President Rock Island Coal Co., and Coal Valley Mining Co.): Mr. Bement's investigations and discussions are of much value and interest, but I am of the opinion that sufficient time and attention has now been given to the Heine and other water tube boilers and the different settings of these types, and I would advocate that the members of this society make a more thorough study and devise improvements for the boiler plants now in existence containing return tubular boilers. From what I can learn there are about 6,000 high pressure boilers in the city limits of Chicago. Of this number 350 plants generate 500 H. P. or more. I am unable to say how many boilers are included in the 350 plants, but feel safe in estimating six boilers would be a fair average; hence, there are 3,500 boilers in about eight times as many small plants composed largely of single or double units. It is possible that the 350 large plants generate the majority of power and do so under economical and favorable conditions from the standpoint of the smoke nuisance, and the most good can be accomplished by remedying the smoke evil in the small plants, because of their number.

Sometime ago I attended a meeting of this society when the Chief Engineer of the Stratford Hotel Company made a statement which impressed me very favorably. He had certain conditions to meet and he solved this problem after having thoroughly analyzed his conditions. This is what I think the members of this body should do to a greater extent. It is far from my intention not to give Mr. Bement's article read tonight all possible credit, but it is nothing more than a recitation of facts which have been developed a great many times, not alone before this body but at the University of Illinois at Champaign, where boiler plants of the Heine type were perfected to such an extent as to be practically smoke proof, or better said "fool" proof. I differ with many of my scientific friends

as to the remedy of the smoke evil. That water tube boilers with special settings, give good results, and undoubtedly more economically, is willingy agreed to; yet we cannot expect to shut down every boiler plant in the city and install Heine boilers or other preferred types. I do not think that the city can adopt ordinances to that effect, and I do not believe it will do so, because the industries of this city are of much importance and are entitled to reasonably lenient treatment at least. Speaking for the producers of coal in Illinois and Indiana and at the same time for the fuel consumers of this city, who are entitled to purchase their coal at the lowest cost, and the railroads by whom I am employed as Mining Engineer, who carry a large part of the coal to this city, I appeal to this body to devote more time and attention to the proper setting of boilers now in existence. The repeated arguments regarding the Heine water tube boiler may create the impression that that type of boiler alone is capable of producing the result which we seek to establish. It is my opinion that while I do not desire to depreciate the value of the Heine boiler, the same results can be accomplished with other boilers. As a parallel case, I may say that if all the doctors in the city would prescribe the same patent medicine for the various kinds of illness that human fleh is subject to, we would soon have no use for doctors and their prescriptions. I am, therefore, an advocate of a study of conditions existing and the application of the remedy as befits the case.

I have been investigating various so-called smoke consumers, and preventers, and am frank to say that I think some of them accomplish their purpose. The underlying principle of all successful preventers I am familiar with is the application of either forced or induced draft. Several of my friends have ridiculed the fact of my interest in these devices, on the claim that a properly designed boiler correctly set does not need any device. This may be true, but since we have many improperly designed boilers which are incorrectly set and are not properly fired, it seems to me the engineer is the proper party to determine what steps should be taken to make this boiler smoke proof, or at least reduce the smoke so it will not be a nuisance.

Sometime ago a drawing of a device was sent to me for approval, with the request that I become financially interested therein. I passed the drawings around among engineers, and they were returned with statements containing more or less ridicule and sarcasm; nevertheless, this device has been installed to a boiler and the building is now using Illinois coal and makes no more smoke than it did before with Pocahontas coal. I merely mention this to show that we sometimes under-estimate the value of devices and do not deem them worthy of trial or investigation, simply because the principle advocated therein does not coincide with our views.

The coal producers of Illinois are only asking for their rights when they appeal to the Western Society of Engineers that it investigate such plants as are generating obnoxious smoke and study the

modification of boiler setting. There is a large field of labor open to engineers which has not been worked and which will prove profitable, not only to the profession, but to the coal consumers who are now paying high prices for coal brought from other states and which prevents our nearby mines from getting the share of business they are entitled to. The Illinois Coal Operators' Association thoroughly appreciates this subject, and in the constitution recently adopted provision has been made for a committee of nine members to investigate the subject of proper firing of Illinois coal and smoke abatement. I trust that the members of this Society will establish close relations with the Coal Operators' committee and bring about material improvements.

Mr. Walter T. Ray and Mr. Henry Kreisinger, M.W.S.E., (U. S. Geological Survey): This paper gives very important data on the benefits of tile roofs to boiler furnaces,—the gain is about 10 per cent in completeness of combustion.

It is self-evident that when the lower surface of the tubes is covered with tiles it can receive no heat directly by radiation from the fuel-bed, bridgewall, flames, etc. Nevertheless a great deal of heat does pass through the tiles by conduction and is imparted to the tubes by radiation across a fraction of an inch and by direct contact on the sides of the tubes. It will be recalled that the Nernst Lamp utilizes the fact that the metalic oxides become excellent electrical conductors at high temperatures; it is a general law of physics that heat conductivity increases along with electrical conductivity. In the case of fire-clay this increase is quite rapid, probably, so that at high furnace temperatures the amount of heat reaching the tubes through the tiles must be large. It would be very interesting to see some laboratory investigations made on the heat conductivity of all kinds of fireclay products at various high temperatures. Undoubtedly the best "Dutch Oven" of today could then be improved.

The lowest row of tubes in a Heine boiler does far more work than any other, even when completely encased in tiles, as is shown by direct measurements described in a paper read before this society March 20, 1907, by Prof. L. P. Breckenridge, entitled "A Review of the United States Geological Survey Fuel Tests under Steam Boilers."

We wish especially to point out the fact that the vital point in Mr. Bement's paper is the difference in the unaccounted for items with and without the completely encased tubes. Comparisons between boiler performances for the purpose of obtaining data on incidental features should either be made on boilers and settings exactly the same in all other dimensions, or else some function should be selected as an index which is directly dependent on the feature investigated. Mr. Bement has done this by calculating the percentage of loss due to incomplete combustion. It is especially dangerous to compare boilers on the basis of area of heating surface. For instance, two boilers of the B. & W. type, exactly alike in length, diameter and

number of tubes, and of the same number of rows vertically, having as their only difference the distance apart of the tubes in the rows horizontally, may have very different boiler efficiencies. It is very probable that the narrower boiler with the tubes closer together will have the higher efficiency, for the reason that the gases will pass between the tubes at a higher velocity, and hence will impart more heat to them. The other factors influencing heat absorption would be the same in both cases on the average,—these factors being density of gases and temperature difference between gases and water.*

Dr. D. T. Randall, (U. S. Geological Survey, Washington, D. C.): There is one thing which has been touched on that I might add to a little, and that is in regard to the unconsumed gases. Some one asked the question as to how much that might amount to. The Manchester, England, Committee for Testing Smoke-preventing Appliances went into this question of smokeless combustion, and made some analyses of the many plants smoking and those not smoking, to determine whether there were combustible gases being lost or not which accompanied the soot. It was found that in practically all cases where smoke was present there was a loss due to carbon monoxide, and often there were other combustible gases such as hydrogen, methane and ethylene shown in the analyses. The losses which may be calculated in the heat balance due to those gases may amount to as much as 10%; and sometimes under bad conditions to much higher percentages. (For discussion of this subject see page 101, U. S. Geological Survey Bulletin No. 325, "A Study of 400 Steaming Tests"). The radiation losses from the boiler seem to be a disputed question, because the radiation taken by itself is a difficult thing to determine. It is generally assumed to be about five per cent. and from all the information which we have been able to gather, it probably is not much less than three per cent. as a rule.

I might say, in connection with the United States Geological Survey tests mentioned tonight, that there was almost always a high unaccounted for loss, which seems to be in part due to incomplete combustion of the gases. This unaccounted for loss amounted in most cases, to 8% or 9%. The furnace used was a hand fired one and some of the loss was probably due to the hand firing. It is probable that in a chain grate furnace as described in the paper, such losses can be considerably reduced.

Mr. R. H. Kuss, M.W.S.E. (Assistant Smoke Inspector of Chicago): The impression that I get from the paper is not so much from a close study of the paper itself or from the discussions just given, but more from the discussion at my table in the office of the Smoke Department which many of you have visited in the past. I feel that there is a growing improvement in the matter of understanding of the problems involved in the burning of coal. The first people that came into the office spoke as though there was just one problem involved, and that was the boiler, meaning by that a unit

*Journal Western Society of Engineers, Vol. XII, page 12

in itself. Later, people have indicated to me that this paper and some others that have appeared before are responsible for an analysis of the subject under two heads, as pointed out by Mr. Harrington; heat generation is one division of the subject and heat absorption is another. Perhaps one which he did not mention, though also very important, is the operation and maintenance of the apparatus. The paper, as I take it, emphasizes that you must segregate the two processes of heat generation and heat absorption. The separation of the two processes is accomplished in the case of the Cedar Rapids installation by the interposition of a tile roof. Unfortunately, when we adopt the tile roof we are likely to sacrifice something else unless we are very careful. If we should sacrifice effective heating surface by adopting a tile roof, we might well expect to reject the system. However, in this particular comparison, the overall results of the two systems of baffling seems to be in favor of the tile roof. Let us grant for the time being that the Fisk Street station boilers are better adapted to heat absorption because of the baffling treatment; the argument then simply results in the conclusion that the furnace efficiency of the Cedar Rapids boiler is even higher than that represented by the difference between the overall efficiencies of the two settings compared.

Having found a way to improve the heat generation efficiency, the next step is to conserve as high a boiler efficiency as possible. Referring to Fig. 1, this might be accomplished in part by the extension of the second flame plate in the gas path so as to take in all of the tubes instead of cutting it off on its lower end as was done. Of course, this would necessitate the raising of the boiler away from the arch which would have to take the place of the tile roof so that an adequate opening from the second to the third pass could be obtained. Add to this a manner of placing the transverse flame plates so that less and less heating surface is encountered at every succeeding section of the gas passage (agreeing to some degree with the loss in temperature and volume of the gases) the heating surface could then be made more effective than for either of the cases shown in Fig. 1 and Fig. 2.

All of this simply means to me that in order to make a great deal of progress we must endeavor to find out for any case what the furnace does as a furnace and what the boiler does as a boiler; then after a year of experience find out whether the manner of installation selected as a combination is excessively difficult to maintain and keep clean thereby offsetting some of the gain by selecting the most economical operating setting.

In the matter of draft comparisons occurring in the paper it might be well to remember that the amount of draft over the fire is influenced by the condition of the fuel bed which if heavy, results in a correspondingly higher draft. Where the draft over the fire is increased by reason of the fuel bed condition, the rate of combustion decreases rather than increases with the increase of draft, since

the resistance to air passage through the fuel bed increases and the rate of combustion is dependent to some degree upon the rate at which air passes through the fuel bed. The preceding remarks are true if the fuel bed resistances compared are based upon uniform fuel thicknesses, for, if the draft is relatively lower owing to uneven fires or holes, the result is likely to be low rates of combustion.

Much of the adverse criticism that has arisen during the discussion would have been avoided had a fourth column been added to Table 3, this column representing the figures obtained from the Fisk Street tests that are used in the comparisons.

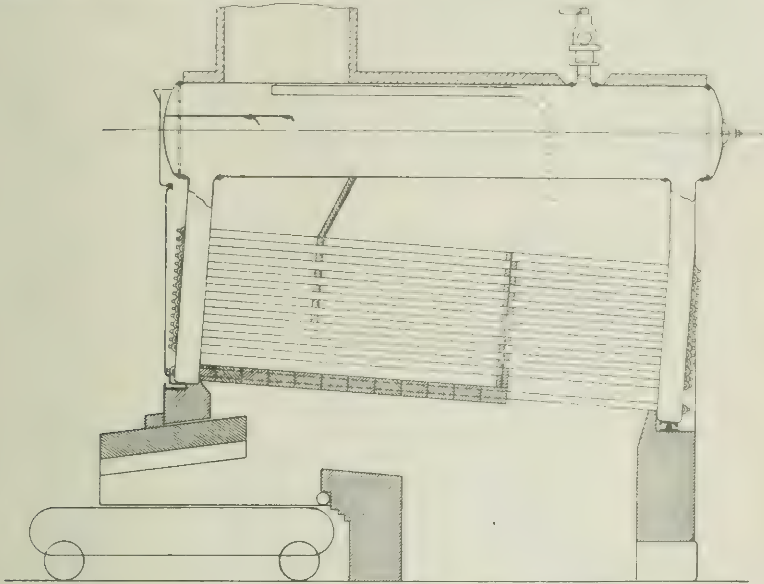

Fig. 7. Box header type of boiler with tile roof and three gas passes.

The discussion of this evening brings out one thing that should not be overlooked. It is entirely wrong to compare the performance of one type of coal feeding apparatus with that of a hand fired plant even though there may be a tile roof employed in each case, unless it is done merely to investigate into the general over-all results. The fact that the United States Geological Survey employed a tile roof furnace, hand-fired, should not be held to be a sufficient cause why the results ought to be identical with a traveling grate in such particulars as the rate of combustion per square foot of grate surface per hour. It is wrong to say because the average rate of combustion on the U. S. G. S. grates was in the neighborhood of 25 lbs. per square foot per hour and a higher average rate resulted in smoke emission that a hand-fired furnace with a tile roof could accommodate only this rate smokelessly for any particular short period. The facts are that with any high temperature furnace, hand-fired, the

rate of combustion is decidedly high immediately after firing, gradually reducing until an average result of the rate found by computation is that of the figures resulting from the use of the total number of pounds of coal burned during the entire test.

Consider now what would happen as to smoke with a traveling grate feeding fuel so that its rate of supply equaled the maximum attained combustion rate of the hand-fired installation. The proportions even of the traveling grate—tile-roof furnace might not be adequate to allow the evolved gases to be completely consumed, and might possibly result in objectionable smoke to nearly the same degree as is met with in a hand-fired plant with the same proportions existing in the combustion chamber.

The writer of the paper deserves a good deal of cerdit for bringing about an installation that in the first place takes into account the advantages of an efficient furnace and in the second place conserves the usefulness of the boiler by an ingenious application of gas-baf-

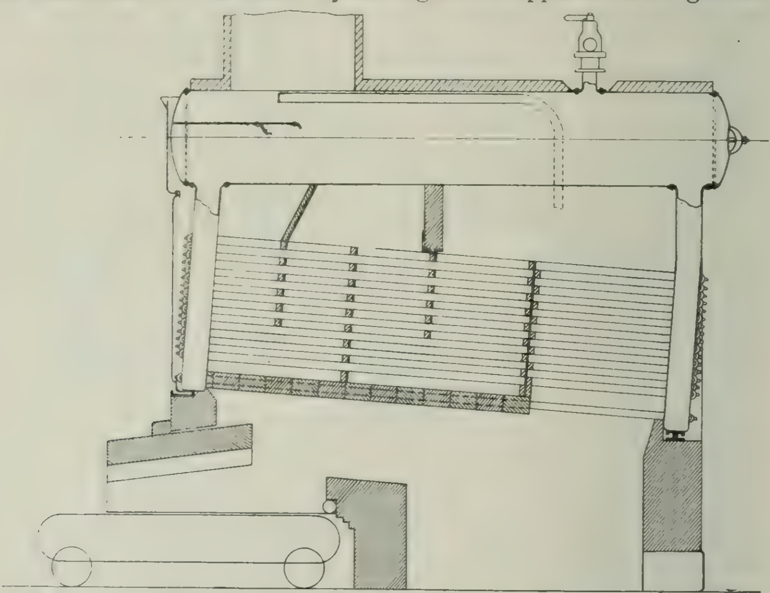

Fig. 8. Box header type of boiler with tile roof and five gas passes.

fling well calculated to overcome some features about which there has long been controversy. It must be through the selection of the best furnaces connected up with boilers properly baffled that substantial progress in the economical use of coal will eventually be brought about.

Mr. W. J. Williams, (Chicago, Edge Moor Iron Works): In order to insure the success of any project, it is necessary to have cooperation. It is well known that in order that we have a successful novel, the reader must collaborate with the writer, the audience with

the actor, etc.; so with engineering problems, the manufacturer must collaborate with the engineer. Of course, all up-to-date manufacturers have a large engineering force, but these men must necessarily work in a rather restricted field and not have the opportunity of meeting all subjects and engineering conditions in the same manner as the consulting engineer.

In the early part of 1906 Mr. Bement asked us if we would build a boiler for the Cedar Rapids & Iowa City Ry. & Light Co., conforming to his designs shown by Figs. 7 and 8, which embodied the essential features of that shown in his paper. We told him that we would and submitted the design, Figs. 9 and 10. When some of our

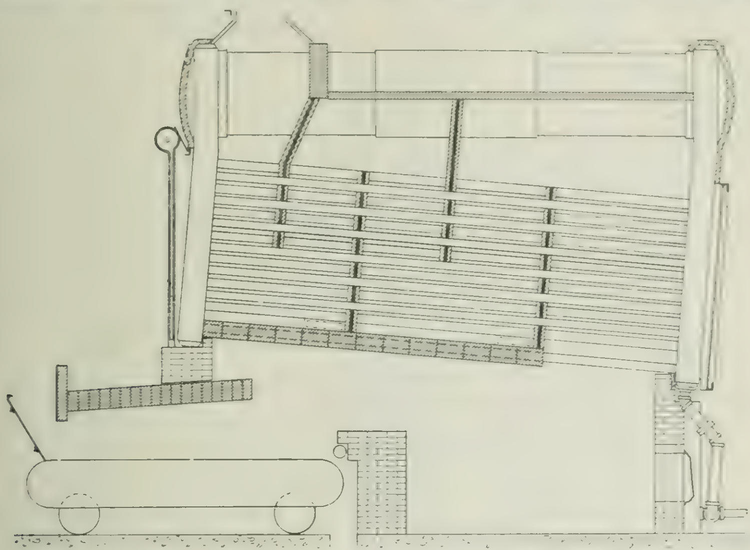

Fig. 9. Edge Moor boiler with tile furnace and five gas passes.

competitors learned that we were willing to do this, and in order to make the sale of their boilers, they also agreed to employ a tile roof and were willing to conform to his demands, although we understand they made serious protest. Unfortunately, we were not successful in securing this business, but since then we have used the scheme of baffling and the tile roof with excellent results.

For the Western coals which are high in volatile carbon, it is necessary to have some type of furnace where the combustion will be complete before the hot gases strike the colder surface of the boiler, and we believe that Mr. Bement's scheme is the best method that is known of at present, as it combines the horizontal furnace roof with the vertical flame passes.

We have used and are installing this system of baffling in the following plants:

Continental Realty Co., Milwaukee, Wis.
Cook County Insane Asylum, Dunning.
Hills-Benedict Linseed Oil Co., Chicago.

We have also used and installed boilers with the encircling tile and a modified form of baffling at the following plants:

J. V. Farwell & Co., Chicago.
Minahan Building Co., Green Bay, Wis.
Medinah Temple, Chicago.
Chicago Title & Trust Co., Chicago.
New York Life Bldg., Chicago.

The installation in the Medinah Temple is shown by Figs. 11 and 12.

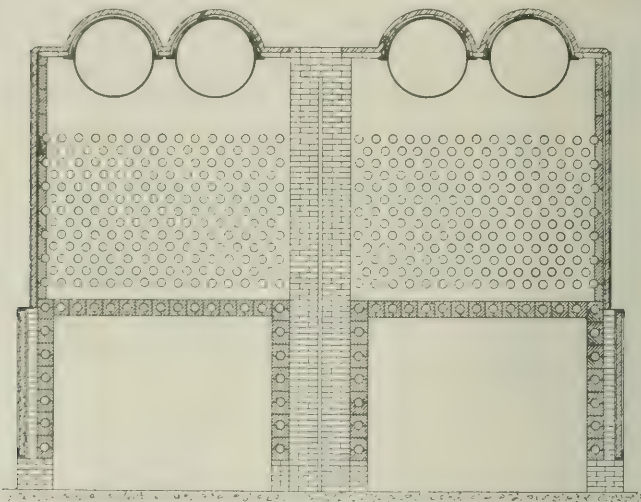

Fig. 10. Cross section of Fig. 9 showing Edge Moor boiler with tile furnace.

Mr. Joseph Harrington, (Chicago, Superintendent Green Engineering Co.): I cannot enter into any careful analyses of the figures contained in the paper, but I believe that Mr. Bement handled this subject as it is ordinarily handled, by considering the entire boiler and its setting as a single unit. That is the customary way. Handling it in this way renders it rather difficult to separate the various operations of production and absorption of heat.

The stoker and its furnace are for the purpose of producing the heat, and the boiler is for the purpose of absorbing the heat—quite contrary operations—and it seems to me that in any intelligent discussion of efficiency, these two parts of the subject should be separated. The figures for efficiency, as outlined in the paper, cause some doubt in my mind, because of the different initial conditions, or conditions at the point of entrance to the heating surface of the boiler. The tests were carried on at quite different rates; the flue gas analyses were quite different; the conditions surrounding the

operation of the coal combustion were different, so that I do not see how the two boilers by themselves, considered merely as absorbing machines, can be directly compared. Whatever difference is found in these two series of tests I believe to be due entirely to the furnace

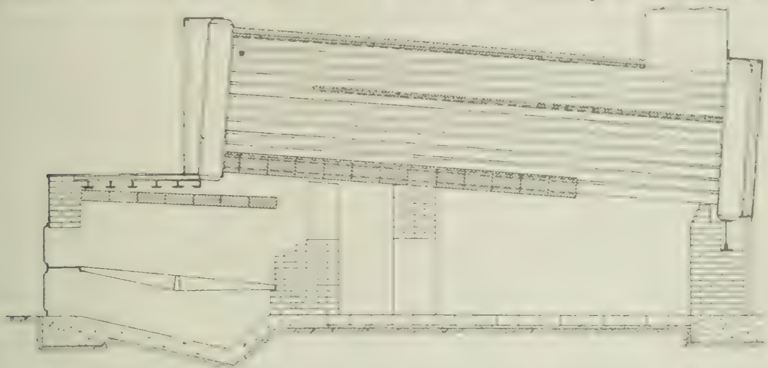

Fig. 11. Edge Moor boiler and tile roof furnace in Medinah Temple, Chicago.

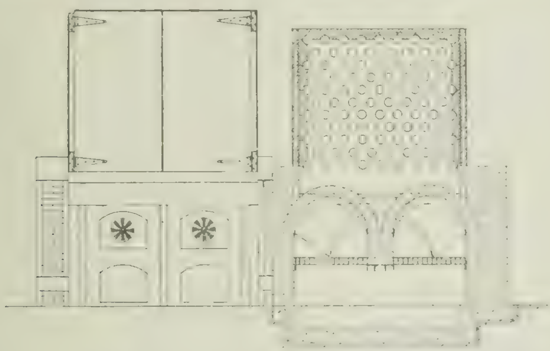

Fig. 12. Cross section of Fig. 11.

conditions. The Cedar Rapids setting was more or less leaky, the water back was set higher than it should have been for the efficient operation, the low CO_2 in the flue gases would indicate the infiltration of cold air, the lack of smoke would indicate more or less perfect combustion; all of these things would indicate quite a different condition at the entrance to the heating surface of the boiler. It would seem to me, therefore, that the question of the relative efficiency of these two settings is entirely a question of the relative efficiency in the process of burning the coal.

Now there is a difference of about 10% in the heat, which is classified as radiation and losses unaccounted for. This item would probably be analyzed as consisting of unconsumed carbon—carbon monoxide—and incompletely consumed hydrocarbons. These combinations of hydrogen and carbon were present and as hydrogen has

a strong affinity for oxygen it is burned before the pure carbon of the smoke is oxidized. Consequently wherever the smoke is entirely eliminated it is a fair assumption that the hydrocarbons contained in the same gases have been consumed. If this assumption is correct it simply means that smokeless combustion is efficient combustion. Therefore this comes back to the problem which you probably have heard mentioned—the smoke question. If these gases were burned to a smokeless condition, the probability is that the combustion was much more efficient than in the case where much more smoke was produced.

I am not going to discuss the question of smoke prevention at this time, but the tile roof furnace as shown in Fig. 1, in connection with the chain grate, is the primary reason for the smokeless condition of the gases and consequent higher efficiency of the setting. Now, whether it is necessary that this particular tile roof furnace should be produced by hanging tiles on the lower row of tubes, or whether it could be produced with equal efficiency by a flat arch or other form of arch in a Dutch oven entirely in front of the boiler, I believe to be easy to answer. It is merely a question of producing complete combustion of the gases and consequent economic combustion. The necessity for this particular form I do not believe exists. There are many installations of chain grates in Dutch ovens with the vertical pass type of boiler silimar to that shown in Fig. 2, the standard setting of the B. & W. boilers, that are absolutely smokeless, and I therefore question the contention that to produce a high economy and smokeless condition of the stack this particular setting is essential. There are other ways of producing this condition which are actually in existence.

President Abbott: In this connection it might be of interest for me to read a paragraph which appeared in one of the evening papers today:

BLOW FOR SMOKE LAWS.

"The smoke ordinance of Chicago was dealt a blow by a decision "of the Supreme Court handed down today in the case of the city "against John E. Knobel and the Heyworth Building, in which the "decision of the Municipal Court finding the defendant guilty of "violation of the ordinance is reversed. The ruling of the upper "court upholds the contention that no matter how great the smoke "nuisance it is only necessary for the perpetrator to show that he "has installed the latest devices to abate the nuisance and is doing all "in his power to make them effective."

HOLDS CITY COURT ERRED.

"The Supreme Court held that the Municipal Court erred in ex- "cluding from the trial evidence showing that the defendant had "made use of the latest smoke-consuming plants. The court says: "'It appears plainly from the record that no method has been found "by which in large buildings it is practicable to install a plant that "sometime during the day will not emit smoke and gases.'"

I think that decision is the best thing which ever happened to the smoke crusade of the city. It will put the officers of the Smoke Department on their metal to ascertain what will produce smokeless combustion, and to prescribe to the coal users such a design for their furnace as will produce those results. Heretofore it has only been necessary for the smoke inspectors to testify in court that at two o'clock last week there was smoke issuing for five minutes from a stack at a certain location. That was a matter of perhaps some interest to the victim, but it did not at all assist him in determining how he could prevent that condition. With the decision which is handed down today, I think we may see light breaking through the smoke.

Mr. E. F. Osborne: I have not had the opportunity of going through Mr. Bement's paper as thoroughly as I woud like to, but in view of the fact that this discussion has drifted off a little, possibly I may be allowed to follow, especially in view of the fact that it has drifted into the "smoke" question.

Some 17 or 18 years ago I had occasion to build two plants. They were both of about 1200 horsepower, and it happened both used the same type of boiler. My instructions in one case were to build as good a plant as I knew how, and almost regardless of expense. Fuel cost us 80 cents a ton delivered. I have watched that chimney many a time and could not tell whether there was a fire there or not. At the same time, as I stated above, I was building another plant of about the same size which happened to be a plant for making ice, in which the owners of the plant were after "output." It was suggested by me that we might make ice at a certain price. The man who was paying the bill said, "I do not care what the ice costs, I want output and I want it quick." If you can get such and such an output I can get as a bonus 50 cents a ton for the ice from my plant and also for the ice from all the other plants in this place." It was then about the first of February; the plant was to be in operation about the 1st of May, and we got it started at about that time. The coal cost us $3.25 a ton. I have seen smoke pouring out of that stack and casting a black cloud over the city for two and a half miles. Now the point is this—if the engineer is given money enough, and if he is given room enough, he can build a plant that will *not* produce smoke.

When I first came to Chicago in nearly all the buildings that were heated by steam, the space from the grates to the boilers was about 12 to 14 inches, as in Mississippi River practice, and the architects would not allow any more, thinking that this height or less was about right. The consequence was we had a volume of smoke pouring out that could be seen for miles. But this is getting off of the subject, I presume.

Smoke is not all black, as Dr. Evans knows. There is another element that has a very serious effect, and that is the amount of sulphur. Of course much of our Illinois coal has a large amount of

sulphur. That, I think, has fully as deleterious an effect, and more so from the health standpoint, than the amount of carbon in the air.

Dr. W. A. Evans, (Commissioner of Health, Chicago): I am not competent to discuss the questions under consideration this evening. I am here only to learn something about the method of smoke prevention as you see it, and do not feel altogether at home in this assembly of engineers.

You know that I belong to a profession that is supposed to disagree. I have attended a good many medical meetings, and never attended a more typical one than this tonight. The disagreement is as apparent as in any medical discussion I ever heard. I had supposed that engineers were able to arrive at conclusions without so much difficulty.

The question before you this evening from a purely technical standpoint—from the standpoint of the relative efficiency of different types of furnaces and boilers—of course I am not competent to discuss. We are much interested, however, not only in my branch of the city government, but in all of the branches, in the purification of the air. When we come to study my side of it particularly, I find that we are just as much at sea as some of your members appear to be in their line.

For example, we do not understand the relation between air pollution and disease. There seems to be a reasonable probability that there are certain diseases such as consumption which are contracted from the pollution of the air, and there are studies which tend to show that there is some demonstrable relation, but yet the technique is not well understood, except that the trouble appears to be in proportion to the total quantity of impurities that may be in the air. For example, in analyzing the air to determine its degree of pollution, we are accustomed to take carbon dioxide as a standard by which the safety or lack of safety of the air is determined. Yet we realize the fact that the carbon dioxide is only an approximate measure by which the degree of the pollution is determined.

While the smoke problem in this western portion of the country is more acute than in any other, I remember that at one time in New York people were protesting against cinders from the stack of locomotives using hard coal. The point was, that these were more annoying to them than the soot about which we complain, and the people were praying for the use of soft coal, and we out here are praying for the use of hard coal, and I find that the different people who have investigated this question appear to have come to a series of conclusions. I believe there has been smokeless firing of boilers with all kinds of devices. I believe that perhaps the largest part of the problem rests with the man directly in charge of the boiler, and I feel that we will not competently meet the question in this country until we have a school for training firemen, of a different standard than at present. I believe the regulation of smoke consumption will not be productive of a maximum amount of good until it recognizes

the fireman as a factor in the prevention of smoke, and a legal cognizance of this reason, because every boiler is a law unto itself, or rather boilers will fall into groups and we cannot view the whole smoke problem as a single proposition. I do not believe it would be possible to build a stoker that will handle all types of coal.

I have been especially interested in this subject from a sanitary standpoint, that of the man whose clothes have to go to the laundry to be cleaned, the man whose house has to be painted, etc., in addition to its medical phase, but I learn here tonight, that it is also a matter of economic importance to the coal user. I believe that there is a general recognition of the fact that those owning boilers are trying to make as little smoke as possible, but often after spending a great deal of money in what he believes to be a solution, an owner comes to find that it has not proved to be so as far as his particular plant is concerned. I believe there is more necessity for patience on the part of everybody than we have had in times past, because it cannot be said that we are ready in this or any community for a final solution of the smoke problem.

At a meeting in Providence a gentleman said that we need more research than administration, and I believe that is true of this question of smoke. I believe that through meetings such as this and research studies such as these, there will eventually come the solution of the problem.

Mr. Alexander Prussing, (Chicago, Pittsburg Meter Company): Concerning the remarks by Prof. Breckenridge regarding the general proposition of using meters in boiler tests, I take the liberty of stating as follows, so that you may have the matter from our standpoint, because I think an injury will be done all concerned should an erroneous interpretation be placed upon such criticism as made by him.

The statement made by Prof. Breckenridge that he has tried on several occasions to justify the use of hot water meters for boiler testing but with disappointing results is probably due to incomplete experience and possibly to the use of hot water meters under unfavorable conditions, particularly such conditions as are beyond their reasonable mechanical capabilities. It is a well known fact that ordinary wear of the working parts and cylinder of a hot water pump is many times greater than that of the same parts in a cold water pump for the same amount of discharge. The comparison applies equally to hot water and cold water meters. The necessity for metal parts in a hot water meter in place of hard rubber in a cold water machine increases their weight and there is a greater libility to unsatisfactory operation, by reason of the cutting effect of minerals which are precipitated in many feed waters, and from other foreign substances passing through the measuring chamber thereby greatly increasing the wear.

Never will satisfactory results be obtained from a hot water meter which is not in good repair and accuracy must not be expected from

the machine no matter how perfect it may be when large amounts of foreign substances are passed through it with the water. While Keystone meters are provided with a strainer, at the inlet port, which prevents the introduction of such large particles as might immediately prevent the meter from operating, yet in waters where there is great mineral precipitation the accumulations soon become manifest if the machine is kept in continuous operation without being cleaned. Metal pipe cuttings, cotton threads from pump packing, slivers from piston rings, charcoal, sand and gravel from settling tanks, metal from walls of pipes in various stages of decomposition and deleterious boiler compounds all find their various ways to lodgement in the hot water meter. As a rule the plant operator knows little or nothing of the solids carried in the feed water until he becomes the owner of a hot water meter. When its working parts refuse to move he concludes that the meter is good for nothing and condemns it to the scrap heap. Sometimes he is wise enough to himself look for the cause and sometimes he has the courtesy to notify the manufacturer that the machine is not giving satisfaction. In such instances he generally learns something about the correct use of hot water meters. We do not advocate the continuous use of hot water meters on boiler feed services, but recommend their use only for periodical tests that the quantity of water evaporated may be checked from time to time. Even with this intermittent use, when cut out of service, the meter should be cleaned and examined for abnormal wear. Calibrations should be made at the beginning and closing of a test to determine the correction for the indicated meter readings. When rightly handled the hot water meter is an invaluable agent in definitely determining boiler efficiency and is the only satisfactory means of recording evaporation in boiler tests. Notwithstanding the cost of maintenance, intelligent steam users find it desirable to install these machines because they are a determining factor in preventing waste and reducing fuel consumption. Should it be desirable to obtain continuous readings and expense of equipment is a minor consideration, a battery of meters can be installed and used in rotation so that periodical investigations and repairs may be made and the installation may be kept at all times at its highest efficiency. For ordinary plants one or two meters intermittently used will serve to establish accurate evaporation averages or determine the relative values of different fuels during a period of time usually devoted to experiments of this character. To obtain accurate results the operator must have a perfect knowledge not only of the service conditions but also of their effect on the meter. With this equipment the proper use of a hot water meter can be made a source of definite and invaluable information.

Mr. Edward H. Taylor, (Chicago Fuel Engineering Co.): Regarding the discussion following the presentation of Mr. Bement's paper it appeared to me that instead of the results actually obtained from the steam generator being discussed, attention was largely

given to discussing the author's methods of calculating the comparison between it and certain tests previously made on other apparatus.

As one who is very much interested in this subject and as the representative of the consumer, I should think that those who are anxious for smoke suppression and economical combustion would be interested in knowing definitely whether or not this improved boiler was more efficient than the Standard Vertical Pass settings, and also if its operation resulted in making less smoke.

These features, however, the critics appeared to entirely overlook, and I would like to know whether or not the claims made for this improved boiler are true. On the face of the matter it appears to me that the critics were satisfied that the test records were accurate, otherwise they would have discussed the subject adversely.

As far as test records on the improved boiler are concerned, I can vouch for their accuracy because of my company's participation in the work, but I have no knowledge of those made on the Babcock & Wilcox boilers.

Regarding the question of smoke, I, personally, am fairly well satisfied that the improved boiler setting is superior to the regular Babcock & Wilson setting, but I would like to know whether it prevents smoke at the expense of efficiency and capacity.

Mr. Geo. W. Nistle, (North Muskegon, Mich.): In general my practice during the last decade agrees with that of Mr. Bement in the design of setting of boiler No. 10. I have used a number of settings of water tube boilers of the standard B. & W. type and have not been satisfied with them. One feature which I have found to be particularly undesirable is found in most water tube settings and in the boiler No. 10 also. I refer to the vertical baffles. These I have found to be very difficult to keep in repair and in several instances I have found them in operation with big holes in them, short circuiting the gases. Repetition of such discoveries after I have turned plants over to their owners has driven me to the use of the horizontal baffle, using the top and bottom rows of tubes for support.

The great excess of heat usefully employed in making steam by the No. 10 boiler over that similarly employed by the Fisk Street boilers, is such as to suggest the question why? It might be that boiler No. 10 had greater absorbing capacity. On the other hand it might be that the combustion was more complete. I am inclined to the latter view for the following reasons:

a. The boilers are almost identical in construction.

b. The hot gases are applied in the same manner; there being only a difference in the direction of the flow, each setting having just the reverse of the other.

c. The difference between the ratios of steam and flue gas temperatures is very slight, 1.5 for the Fisk Street boilers and 1.480 for No. 10.

It is to be regretted that the setting of No. 10 was leaky, as this impairs our view of the relative perfection of combustion in the two

cases. Assuming that the better performance of No. 10 was due mostly to better combustion, (some of it might be due to the reversed flow of gases), the fact that both fires are covered, over most of the grate surface, by ignition arches, and that No. 10 had, in addition a tile roof over most of the space to the rear end of the setting; would not the better combustion indicate that combustion is not completed in the fire box? (as is claimed by some well known boiler and furnace men.)

That the tile roof furnishes a means for completing combustion only partly finished in the fire box, is shown by an inspection of such a roof in action.

The requisites for the best combustion appear to the writer to be:

1. A proper amount of fuel;

2. A proper amount of air;

3. A properly high and properly maintained temperature;

4. A proper amount of space;

5. A proper length of time spent by the gases in the proper space at the proper temperature.

Mr. Fred C. Boegershausen, (Chicago, Parker Boiler Co.): I was very much interested in Mr. Bement's paper and I am glad to contribute some discussion. I therefore send you herewith a tracing showing a boiler, Fig. 13, built for the Globe Company of this city which is equipped with tile roof furnace; the method of firing is by hand and as far as smokeless combustion is concerned, it is very successful.

The question, "Is a tile roof furnace an absolute necessity in the way of preventing smoke," has repeatedly been made to the writer recently by progressive purchasers and others interested in the abatement of smoke. I feel safe in replying that the tile roof is certainly contributory toward smokeless combustion. In this connection I might say that we recently ran a test at the plant of the John Gund Brewing Company, La Crosse, Wis., on a 306 H. P. boiler of our make, equipped with a traveling grate stoker. The boiler was not equipped with a tile roof furnace, simply having our standard baffle tiles over the lower row of tubes. The chain grate stoker, however, has a five foot arch which is as usual built out in front of the boiler.

The fact of course must be considered that we baffle our boilers horizontally, this method exposing only a part of the lower row of tubes to the gases as they leave the furnace. In this test we developed 149% of the boiler's rating continuously for eight hours and the stack was absolutely smokeless. The efficiency in this test was extremely high even at this overloaded capacity and it is a question in the writer's mind whether or not a higher efficiency could be obtained by enclosing the bottom row of tubes in baffle circle tile. However, we are going to equip this boiler with a tile roof furnace for experimental purposes and shall be glad to report our findings at a later date.

In conclusion I might state that I do not think it would be possible to run the boiler at the Globe plant, which is hand-fired, without the use of the tile roof furnace and keep within the smoke ordinance of this city. It is unquestionably a success in that instance.

Mr. McDonald: Mr. Bement presents certain tests and deductions from the Fisk Street Station. I would ask him to remember the conclusion that the boiler represented by Fig. 1 will give better results than Fig. 5, and some of the speakers have intimated why that is so. In studying the furnace construction and grate construction of those two boilers they are identical in each case, and therefore I am driven to the conclusion that it is in the radiation in the

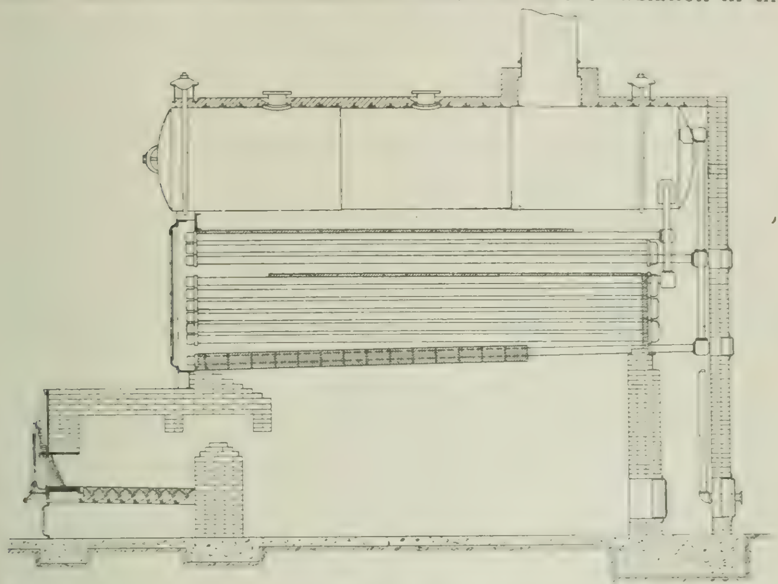

Fig. 13. Parker boiler with tile furnace roof at laundry of Globe Company, Chicago.

boiler itself that this high efficiency or difference in efficiency is obtained.

In studying the question of furnace construction, the furnace efficiency in this case is assumed to be the same as far as the design of the boiler is concerned, and the other part of the boiler where the efficiency may come in is the arrangement of the baffling and water circulation.

In experiments on the transmission of heat in tubes it is generally acknowledged that the best theory which agrees with the best practice is that the hottest water should meet the hottest gases, and in a standard B. & W. setting as shown by Fig. 2 you will notice that this arrangement is obtained, and also in the design, Fig. 5.

But with boiler No. 10 which we are asked to consider as an improved boiler, I would like to have Mr. Bement state whether he

considers that it embraces a feature of importance in boiler design, and whether it would affect the efficiency of the boiler in any way.

Mr. Chas. S. Reed, (Chicago Retort & Fire Brick Co.): It seems to be the consensus of opinion that a higher efficiency is obtainable from a boiler equipped with the oven type of furnace; whether that oven is formed by a sprung arch, or roof of encircling tile suspended from the bottom row of boiler tubes.

As manufacturers of these tile, the question arises as to how thick below the tubes they should be made,—it has therefore been a matter of speculation as to the maximum weight that tubes under working pressure should be compelled to support. From the side of the manufacturer, the more body there is in the tile, the longer would be their life; from the engineers' side, the more body to the tile, the higher the possible furnace temperature, consequently higher efficiency of the boiler.

As the application of these tile is of a comparatively recent date, and the demand for them surprisingly increasing, we feel a standard should be established. We have made various designs in accordance with the ideas of different engineers, but no standard has been worked out, showing from the engineer's standpoint, how much fire clay body, or in other words, dead weight, can safely be suspended from tubes under steam pressure, in order that this higher efficiency may be obtained, and this is something which should be ascertained.

Mr. C. H. McClure, M.W.S.E. (by letter): In his discussion Prof. Breckenridge has compiled a heat balance for Test No. 2 in which the heat accounted for is in excess of 100%, even with radiation excluded. This he appears to offer as evidence that the tests reported were not correct. Inasmuch as I made the calculation for loss in hot gases, an explanation from me is in order. Therefore, I have made the following tabulation which shows a difference in the item of loss in the dry gas, due probably to an error in his method of reasoning:

Heat Balance for Test No. 2

	As presented by Prof. Beckenridge in his discussion		As it should have been presented	
Absorbed by boiler	60.26		60.26	
Stack loss in dry gases	18.32	24.50	14.31	20.49
Loss due to moisture	3.08		3.08	
Loss due to burning available hydrogen	3.10		3.10	
Ash pit loss	16.26		16.26	
Radiation and unaccounted for by difference	....		3.37	
	100.64		100.00	

Even if the radiation loss should be as much as 3% there would still be a small percentage remaining. But so far, there has been no experimental determination of loss due to radiation which is not based largely upon assumption. I suppose Professor Breckenridge derives his estimate of the radiation from the work reported in Bulletin No. 325 of the U. S. Geological Survey, "A Study of Four Hundred Steaming Tests," pages 143-4 and 5. To quote from this paper, "The method used was very crude and was based on the following reasoning," and further on we find the reasoning to consist of certain deductions derived from some experimental data upon the radiation of the boiler drum, front and rear water-legs and a guess at the radiation of the brick setting and the fire doors!

With the idea of throwing some further light upon this matter, I would call attention to certain points in the results presented by Professor Breckenridge.

He says in his discussion of the heat balance, "It is remarkable that the results, when correctly computed show no radiation and unaccounted for balance." If it were a fact that the heat balance showed no radiation and unaccounted for when *correctly* computed, it would indeed be remarkable—it would be more than remarkable, it would be absurd; and the results presented by Mr. Bement could not be accepted as reliable. As a matter of fact, the heat balance offered by Professor Breckenridge is *not* correctly computed. The error evidently arises from a misconception of the formulae given in the A. S. M. E. Code. In the Appendix XXXII of the code, the various formulae for obtaining the loss in dry gases are discussed, and comparison is made with results obtained by computation from the ultimate analysis of the coal. It is noticeable in this computation that *all* of the carbon in the coal produces gas with oxygen from the air, the resulting products being CO_2 and CO. In other words there is no provision for ash pit loss. The carbon *burned* per pound of "combustible" is the only correct figure to use, and, only in case of complete volitilization of the carbon, is it admissible to use the total carbon per pound of "combustible" as given in the ultimate analysis. Now, supposing that there had been an ash pit loss in the example given, then, it is evident, there would have been less gas formed and less air required, and the total weight of gases would have been less.

In the Cedar Rapids Test 2, to which Professor Breckenridge refers, there was 54.24% of "carbon" in the refuse. This means that, of the 0.5454 pounds of carbon fed to the furnace in each pound of coal, 0.1159 pounds of "carbon" was lost in the refuse, leaving for gas making purposes 0.4295 lb. of "carbon" instead of 0.5454 lb. Now, let us apply the formulae of the code, using the correct value for "carbon." In order to do this, it is first necessary to get this new value 0.4295 in terms of "carbon" (burned) per lb. of "combustible."

$$\frac{0.4295}{1.0000-0.2715}=0.5895 \text{ lb. "carbon" per lb. of "combustible"}$$

which produced gas and used air in so doing.

$$\frac{\overset{CO_2}{(11 \times 7.6)}+\overset{O_2}{(8 \times 12.29)}+\overset{N}{(7 \times 80.11)}}{3\,(7.6+0.0)} \times \frac{0.5895}{100}=$$

19.20 lbs. dry gas per lb. of "combustible."

$19.20 \times 440.5 \times .24=2030.25$ B. t. u. loss.

$$\frac{2030.25}{14182} \times 100=14.31\% \text{ loss in dry gases.}$$

If instead of carbon actually burned per pound of "combustible" the total carbon per pound of "combustible" as shown by the analysis is used, the loss in dry gases is 18.17%. I have endeavored to obtain the figure 18.32% as given by Professor Breckenridge, but even when assuming a complete absorption figure, (CO_2+O_2), of 21.0% for the gas analysis, which is impossible, and 74.86% carbon for the "carbon" per pound of "combustible" the result is but 18.20%. However, this slight difference is probably due to the use of a somewhat higher specific heat in the Professor's computation than is authorized by the code.

The loss of much combustible material in the ash pit leads to considerable error in results obtained by the code formula when it is assumed as above, that all of the carbon of the coal is employed to produce gas.

The loss of 20.49% in the above corrected heat balance is approximately accurate, but since the presentation of Mr. Bement's paper, an ultimate analysis has been made of the pure coal in the refuse of Test No. 2, and with this more complete data, the loss is found to be 20.91 instead of 20.49%, which is a very good check. The details of these later calculations follow:

DETAILS OF COMPUTATION OF LOSS IN HOT GASES, CEDAR RAPIDS TEST NO. 2.

ANALYSES OF COAL AND REFUSE

	Coal	Refuse
Moisture	14.61	.....
Ash	12.54	45.76
Carbon	54.54	48.33
Hydrogen, available	2.85	0.66
Sulphur	3.54	2.61
Nitrogen	0.90	0.67
Water of Composition	11.02	1.97
Total	100.00	100.00
B.t.u. (By Mahler Calorimeter)	10332	7522

DATA FROM TEST RECORDS

Coal fed per hour	[illegible]	lbs.
Refuse per hour	687.7	lbs.
Refuse per pound of coal	0.214	lbs.
Boiler room temperature	85.0°F	
Flue gas temperature	525.5°F	

FUEL BALANCE

	Pounds per Pound of Coal		
	Fed	In Refuse	In Gas
1. Moisture	0.1401	0.000	0.1401
2. Ash	0.1254	0.1254	0.0000
3. Carbon	0.5454	0.1034	0.4420
4. Hydrogen, Available	[illegible]	[illegible]	[illegible]
5. Sulphur	[illegible]	[illegible]	[illegible]
6. Nitrogen	[illegible]	[illegible]	[illegible]
7. Water of Composition	0.1102	0.0042	0.1060
Total	1.000	0.2414	0.7586
8. B.t.u.	10312	[illegible]	[illegible]

1. *Moisture*: All hygroscopic moisture fed to the furnace is evaporated and forms part of the flue gas.

2. *Ash*: The quantity of ash fed is the total ash of the coal. A certain portion of this is lost in the combustion chamber and in the slag on the bridge-wall and sides of the furnace. The amount of ash which is lost in this way may be obtained by subtracting from the total ash fed, the ash found in the refuse which is weighed out from the ash pit. In this instance, it amounts to the difference between 0.1254 (lbs. of ash per lb. of coal) and 0.0979 (lbs. of ash per lb. of refuse) which is equal to 0.0275 lbs. ash.

3. *Carbon*. 4. *Hydrogen*. 5. *Sulphur*. 6. *Nitrogen* and 7. *Water of Composition* were determined in the coal and refuse by analysis. The quantities of these constituents found in the refuse are deducted from the respective weights of carbon, hydrogen, etc., in the coal to obtain the quantities for the calculation of the flue gas composition.

8. The *Heat Value* of both coal and refuse were determined by the Mahler calorimeter. The difference represents the heat delivered by the furnace.

LOSS DUE TO HEAT CARRIED AWAY BY THE HOT FLUE GAS.

Composition of the Flue Gas.

To calculate the composition of the flue gas, the weight of the various constituents of the coal which are given in the third column of the Fuel Balance under the caption "In Gas," are taken as a basis.

Carbon Dioxide.

Carbon per pound of coal × 3 2/3=lbs. of carbon dioxide. 0.4420 x3 2/3=1.6206 lbs. CO_2.

Carbon per pound of coal × 2 2/3=lbs. of oxygen required for combustion. 0.4420x2 2/3=1.1786 lbs. O_2.

Sulphur Dioxide.

Sulphur per pound of coal $\times$ 2=lbs. of sulphur dioxide. 0.0298x2 =0.0596 lb. SO_2.

Sulphur per pound of coal $\times$ 1=lbs. of oxygen required for combustion. 0.0298$\times$1=0.0298 lb. O_2.

Water.

1. *From Available Hydrogen.*

Hydrogen per pound of coal $\times$ 9=lbs. of water. 0.0271$\times$9= 0.2439 lbs. H_2O.

Hydrogen per pound of coal $\times$ 8=lbs. of oxygen required for combustion. 0.0271$\times$8=0.2168 lb. O_2.

2. *From Water of Composition.*

Water of composition per pound of coal=0.1060 lb.

3. *From Hygroscopic Moisture.*

Moisture per pound of coal=0.1461 lbs.

Total Water in Flue Gas.

1. From burning of available hydrogen	0.2439 lb.
2. From water of composition	0.1060 lb.
3. From hygroscopic moisture of coal	0.1461 lb.
Total	0.4960 lb.

Nitrogen.

1. From Nitrogen in coal	0.0076 lbs.
2. From Air required for combustion....	
Burning Carbon to CO_2	1.1786 lbs. oxygen
Burning Sulphur to SO_2	0.0298 lbs.
Burning Hydrogen to H_2O	0.2168 lbs.
Total	1.4252 lbs. oxygen

The proportion of Nitrogen to Oxygen in air, by weight, is 77 to 23.

Hence.—$\frac{77}{23} \times 1.4252 = 4.7713$ lbs. Nitrogen from air required for combustion.

Total Nitrogen 4.7713+0.0076=4.7789 lbs. N

The composition of the flue gas without excess air is then as follows:—

Carbon Dioxide	1.6206 lbs.
Sulphur Dioxide	0.0596 lbs.
Water	0.4960 lbs.
Nitrogen	4.7789 lbs.
Total	6.9551 lbs.

The above gives the composition of gas without excess air. It is then necessary to determine the per cent of CO_2 by volume in the dry

gas containing the above quantities of CO_2, SO_2 and Nitrogen and from this figure derive the excess air for a flue gas of the 7.6% CO_2 composition as reported. As these gases follow the gas laws at ordinary temperatures, the respective volumes per cubic foot at 32 deg. F. may be utilized in computing the percentage composition by volume.

	Wt. Lbs.	Wt. per Cu. Feet	Cu Feet	Percent
Carbon Dioxide	1.6206 ÷	.12268 =	13.210	17.72
Sulphur Dioxide	0.0596 ÷	.17862 =	0.333	0.44
Nitrogen	4.7789 ÷	.07832 =	61.018	81.84
			74.561	100.00

Since the CO_2 in the flue gas as determined by the Orsat apparatus is the sum of CO_2+SO_2 in the dry gas, the dry gas composition by volume without excess air should be expressed as follows:

CO_2 (CO_2+SO_2)	18.16%
N	81.84%
	100.00

There are two values for each, the CO_2 and Nitrogen; one value in per cent of dry gas and the other in weight of each gas. The values 18.16% and 7.60% are both equivalent to the same weight of CO_2 (CO_2+SO_2); and similarly the nitrogen which necessarily accompanies the CO_2 is represented by 81.84% and X%, both equivalent to the same amount by weight of nitrogen.

Hence, 18.16: 81.84=7.6:X, orX=34.25%.

Then the composition of the flue gas containing 7.6% CO_2 is,

CO_2 (CO_2+SO_2)	7.60%
Nitrogen	34.25
Air	58.15
	100.00

The excess air is, therefore, 58.15% by volume, of the dry flue gas; and of the excess air 79% is Nitrogen and 21% Oxygen.

79% of 58.15=45.94 Nitrogen in excess air.

21% of 58.15=12.21 Oxygen in excess air.

The composition of the dry gas is then as follows:

CO_2 (CO_2+SO_2)	7.60
O_2	12.21
N	80.19
	100.00

The weight of CO_2 (CO_2+SO_2) in the flue gas is 1.6802 lb.; Nitrogen is 4.7789.

Hence, 7.6% CO_2 is equivaelnt to 1.6802 lbs.

And, 34.25% N is equivalent to 4.7789 lbs.

The weight of Nitrogen from excess air bears the same ratio to 45.94% as does 4.7789 lbs. to 34.25%.

Therefore, $45.94 : x = 34.25 : 4.7789$ or $x = 6.4097$ lbs. Nitrogen from excess air.

The oxygen from the air is found from the weight of nitrogen, thus, $\frac{23}{77} \times 6.4097 = 1.9146$ lbs.

The composition of flue gas with 7.6% CO_2 is then as follows:

CO_2	1.6206 lbs.
SO_2	0.0596 lbs.
H_2O	0.4960 lbs.
N	11.1886 lbs.
O	1.9146 lbs.
Total	15.2794 lbs.

Loss of Heat in the Hot Gases.

	Wt. in lbs. Spec Heat Rise °F	B.t.u
CO_2	1.6206 x 0.2169 x 440.5 =	154.8
SO_2	0.0596 x 0.1544 x 440.5 =	4.0
H_2O	0.4960 —see below— =	616.6
N	11.1886 x 0.2438 x 440.5 =	1210.6
O	1.9146 x 0.2175 x 440.5 =	183.4
Total		2160.4

Loss Due to the Moisture in the Flue Gas.

Raising 0.4960 lb. H_2O from 85 deg. F to 212 deg. F 0.4960 x 127	= 62.99 B. t. u.
Evaporating 0.4960 lb. H_2O from and at 212 deg. F 0.4960 x 965.7	= 478.99 B. t. u.
Superheating 0.4960 lb. H_2O from 212 deg. to 525.50 deg. F 0.4960 x 313.5 x 0.48	= 74.63 B. t. u.
Total	616.61 B. t. u.

Total Percent Loss on Basis of Heat Supplied.

1. Loss due to Dry Gas $\frac{2160.4—616.6}{8722} \times 100 = 14.94\%$

2. Loss due to Moisture $\frac{616.6}{10332} \times 100 =$ 5.97%

Total 20.91%

If this loss be calculated to "Per cent corrected for Ash Pit Loss" as given in the second column of Professor Breckenridge's compartive table of heat balances, the total loss is 24.76% instead of 29.26 as given in that table.

It is often desirable to obtain a value for oxygen and nitrogen in dry flue gas when the only constituent reported is CO_2, (CO_2+SO_2). A chart, Fig. 14, if drawn on squared paper with appropriate dimensions, may be used to obtain the precentage of nitrogen, and, under such conditions of combustion as produce neither CO nor hydrocarbons the percentage of oxygen may be derived by difference. In

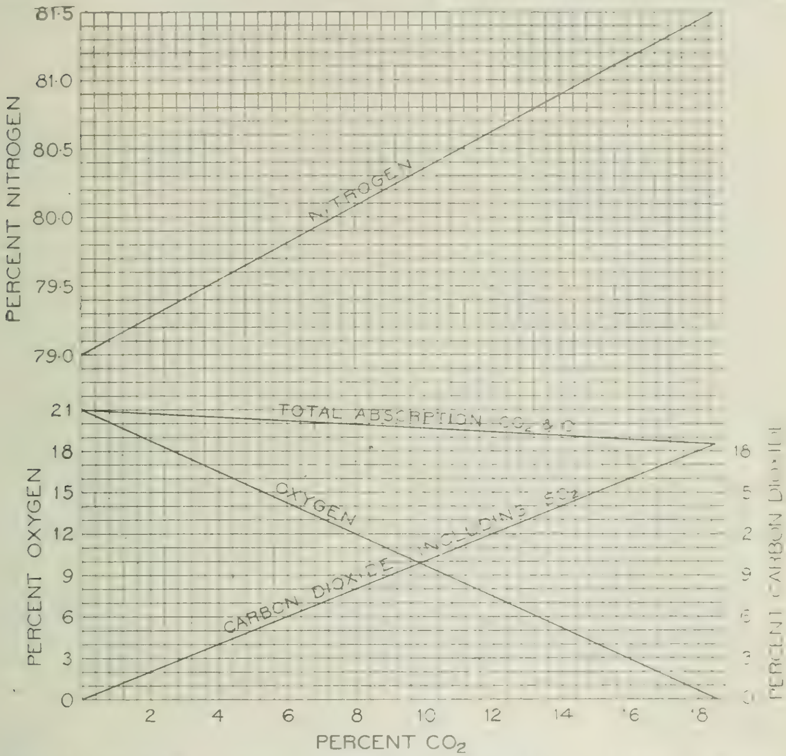

Fig. 14. Diagram showing relative proportions in gases from complete combustion.

Cedar Rapids Test No. 2, for example, only the CO_2 is reported. From the chart the percentage of nitrogen corresponding to 7.6% CO_2 is found to be 80.03%. The difference between the sum of the percentage of CO_2 and nitrogen and 100.00% gives the percentage of Oxygen. The accurary of this method is shown by the following comparative table:

	From Chart.	Computed.
CO_2 (CO_2+SO_2)	7.60	7.60
Oxygen	12.37	12.21
Nitrogen	80.03	80.19
	100.00	100.00

The degree of accuracy of the results obtained from the chart depends upon the completeness of combustion. This particular chart would not be applicable to tests of coals differing greatly in composition from that upon which it is based, but data for similar charts may be easily computed from the analysis of the various kinds of coal. As the total carbon content of the coal increases the sum of CO_2 and O tends to approach the limit 21%, so that, for 7.6% CO_2 on a test of anthracite coal the oxygen would be somewhat greater than 12.37% and the nitrogen be proportionally decreased.

CLOSURE.

Mr. A. Bement: This investigation is unique in having had so many diversified interests engaged in the production of the data, and additional value attaches in that the paper has had the attention of critics who were in possession of all of the information used by the author, which is especially important, for the reason that if there had been error it could easily have been shown.

In arriving at a comparative efficiency for the two boilers, the heat balance, Table No. 7 shows the actual performance as given in Table No. 3. There were two unknown losses which must be ascertained before any conclusion could be arrived at. One is radiation the other incomplete combustion. It is manifestly impossible to get them from the Fisk Street data because of inability to separate the two losses, but from the data applying to improved boiler No. 10, it appears that radiation as obtained by difference, is 2.26 per cent., therefore this amount may be employed to represent radiation for the Fisk Street boiler also, which then leaves by difference, an unaccounted for loss of 9.30 per cent for the Fisk Street boiler.

Thus having determined these two unknwon factors, it is now possible to construct a comparative heat balance, using them with the

TABLE No. 7.

HEAT BALANCE.

BASED ON ACTUAL PERFORMANCE.

	Improved Boiler Average of 4 tests	Fisk St. Boiler Average of 18 tests
Usefully employed in making steam	64.25	62.27
Loss in moist gases, due to		
Moisture in coal	1.68	1.39
Burning available hydrogen	3.15	3.16
Water of combination	1.29	1.36
Loss in dry gases	17.03	17.46
Loss by undeveloped heat in refuse	9.84	2.41
Loss by radiation (by difference)	2.26	2.26
Loss by sensible heat in refuse	0.33	0.21
Loss due to moisture in air	0.17	0.18
Unaccounted for	0.00	9.30
Total	100.00	100.00

other calculated losses, by which efficiency is obtained by difference as shown by Table 8. This is the form of heat balance to which Prof. Breckenridge objects, but fails to give his reason for so doing. It is necessary, however, to base comparison on a condition in which the CO_2 and ash pit loss is equal for each boiler, and this is done by determining the loss in hot gases with a zero ash pit loss, or in other words, for a condition in which all of the coal participates in the combustion process. Therefore, when all of the losses are deter-

TABLE No. 8.

COMPARATIVE HEAT BALANCE.

With 8.99 per cent CO_2 for both boilers on basis of all the coal being burned for each with no ash pit loss.

	Improved boiler based on results of 4 tests	Fisk Street boiler based on results of 18 tests
Usefully employed in making steam (by difference)	74.71	64.27
Loss in moist gases, due to		
Moisture in coal	1.68	1.39
Burning available hydrogen	3.24	3.22
Water of combination	1.31	1.37
Loss in dry gases	16.48	17.86
Loss by radiation (as a constant)	2.26	2.26
Loss by sensible heat in ash	0.15	0.15
Loss due to moisture in air	0.17	0.18
Loss by incomplete combustion	0.00	9.30
Total	100.00	100.00

TABLE No. 9.

COMPARATIVE HEAT BALANCE WITH 16.5 PER CENT CO_2

On Basis of both Boilers using Illinois Midland Coal with a Common Flue Temperature of 525.5 deg. F. and considering all of the Coal as being Burned.

	Improved boiler	Fisk St. boiler
Usefully employed in making steam (by difference)	82.56	64.36
Loss in moist gases, due to		
Moisture in coal	1.76	1.76
Burning available hydrogen	3.09	3.09
Water of combination	1.32	1.32
Loss in dry gases	8.77	8.77
Loss by radiation (as a constant)	2.26	2.26
Loss by sensible heat in ash	0.16	0.16
Loss due to moisture in the air	0.08	0.08
Loss by incomplete combustion	0.00	18.20
Total	100.00	100.00

mined by this process, it necessarily follows that what heat is not lost is employed in making steam. This efficiency by difference appears as 74.71 for the improved boiler and 64.27 for the other. From observation it has been noted, however, that incomplete combustion increases with CO_2, so that gain from high CO_2 is nullified by escap-

ing hydrocarbons,* with the result that on this basis the total chimney loss is constant. This is logical, of course, as it is well known that incomplete combustion increases with reduced air supply unless there is an adequate combustion chamber. Thus in Table 8 the sum of these two losses is 33.14, and as shown in Table 9, the loss in hot

TABLE No. 10.

IMPROVED BOILER.

HEAT BALANCE.

Based on the use of Eastern and Western Coal, with Flue Temperature of 525.5° F. and 16.5 per cent CO_2.

	Illinois Midland Bituminous coal	Clearfield Semi-bituminous coal
Usefully employed in making steam (by difference)	82.56	84.56
Loss in moist gases, due to		
Moisture in coal	1.76	0.04
Burning available hydrogen	3.09	3.49
Water of combination	1.32	0.45
Loss in dry gases	8.77	9.04
Loss by radiation (as a constant)	2.26	2.26
Loss by sensible heat in ash	0.16	0.07
Loss due to moisture in the air	0.08	0.09
Total	100.00	100.00

gases is 14.94. Thus 33.14—14.94=18.20 as the incomplete combustion loss for 16.5 per cent. CO_2. With 9.52 per cent. CO_2, the figure originally given, the heat expended in raising the temperature of the chimney gases is 22.43 per cent., and 33.14—22.43=10.71 per cent. loss in incomplete combustion instead of 10.24 as in table No. 1.

This matter of incomplete combustion loss on the basis of the actual heat balance, Table 7, is illustrated by the diagram, Fig. 15

Table 9 is a comparison on the basis of a minimum flue temperature, as obtained in Test No. 2 of the improved boiler, and 16.5 per cent. CO_2, which serves to show the relative performance under best possible conditions. Table 10 is a comparison on a similar basis between Eastern† and Western coal with the improved boiler.

It has been urged that a comparison between the horsepower capacity of the two boilers, on the basis of draft pressure at the fire, is incorrect, and that it should have been made with draft at the damper. The reason given in support of this objection was, that draft at the fire is influenced by the varying resistance of the fuel bed due to difference in size of coal, etc., but the same argument applies to draft at the damper, although in less measure. Therefore it has been considered best to base a comparison on draft power of chimneys of the same capacity.

Therefore, Table No. 11 gives the comparisons between boilers and their developed capacities based on data in Table No. 3, and

*Journel Western Society of Engineers, Vol. XI., p. 539.

†The composition for the Clearfield coal is taken from Steam Boilers by Peabody & Miller, p. 41.

Table No. 12 traces the process which shows that on a basis of equal chimney capacity the improved boiler is 57 per cent. better, and on

TABLE No. 11.

COMPARISON OF BOILERS AND DEVELOPED CAPACITIES.

	Improved Boiler Average of 4 tests	Fisk Street Boiler Average of 18 tests
Builder's horsepower rating	400	500
Correct horsepower rating	400	552.8
Heating surface in boiler, sq. ft.	4000	5200
Heating surface in superheater, sq. ft.	0.00	960
Heating surface, total sq. ft.	4000	6160
Grate area in sq. ft.	72	90
Ratio of correct horsepower ratings	1.00	1.38
Ratio of grate surfaces	1.00	1.25
Horsepower developed in tests	608.4	742.3
Ratio of horsepowers developed	1.00	1.22
Sq. ft. of heating surface per horsepower developed on basis of 4000 and 5528 sq. ft.	6.57	7.45
Ratio of sq. ft. of heating surface required per horsepower developed	1.00	1.13

TABLE No. 12.

COMPARISON BETWEEN BOILER PERFORMANCE ON BASIS OF DRAFT.

	Comparison based on draft at fire		Comparison based on height of chimneys	
	Improved Boiler Average 4 tests	Fisk St. Boiler Average 18 tests	Improved Boiler Average 4 tests	Fisk St. Boiler Average 18 tests
Draft over fire in inches of water	0.237	0.733		
Ratio of drafts at fire	1.00	3.24		
Horsepower that would be developed with draft at fire of boiler No. 10 for both boilers	608.4	515.0		
Ratios of horsepower developed with equal draft for both boilers	1.18	1.00		
Horsepower developed by boilers of No. 10 type with chimney 130 ft. high and 18 ft. diameter			608.4	
Horsepower actually developed by Fisk Street with chimney 250 ft. high and 18 ft. diameter				742.3
Horsepower that would be developed by boiler No. 10 with chimney 250 ft. high and 18 ft. diameter, according to stronger draft of Kent's formula			843.8	
Ratio of horsepowers developed with a chimney 250 ft. high and 18 ft. diameter for both boilers			1.13	1.00
Horsepower development per sq. ft. of heating surface with equal draft or equal chimney	0.1521	0.0932	0.2109	0.1342
Ratio of capacities developed per sq. ft. of heating surface with equal draft or equal height of chimney for both boilers	1.63	1.00	1.57	1.00

a basis of draft at the fire, 63 per cent. better, which is a reasonably close agreement.

The calculation for draft power of the chimneys is according to the formula of Prof. Kent, p. 427, Steam Boiler Economy, First Edition.

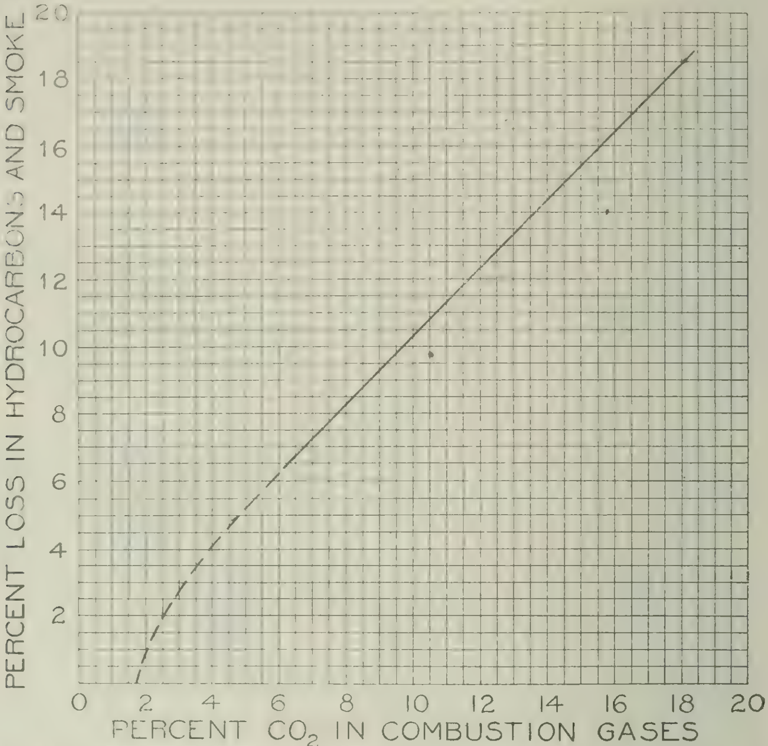

Fig. 15. Diagram showing progress of incomplete combustion loss with decreasing air supply, referring to condition of table No. 7.

The explanation of Table No. 3 should be examined for information concerning some features applying to the author's reply. The various criticisms, however, are replied to in detail in the following sections, which are identified by the name of the person who offered the discussion.

According to Mr. Brydon's statement, his knowledge concerning Fisk Street boiler performance is greater than the author's, and it is certainly to be regretted that he did not take advantage of this and present what he probably considers the truth of the matter, and the fact that he did not do so destroys the force of his statements.

He expresses inability to understand the various "deductions, additions and subtractions," and attempts to reach conclusions on the basis of "combustible burned," notwithstanding which he still seems

to experience trouble because his figure for the efficiency of test No. 1 is higher than that for No. 2, when as a matter of fact these three tests in Table No. 3 which he quotes, show very plainly that No. 2 gave the highest efficiency on the basis of coal burned, or in other words, "combustible burned."

To what extent opinions are influenced by the point of view adopted, is illustrated by Mr. Brydon's criticism of the tests on the Fisk Street boiler, wherein he says they were not "boiler" tests but "coal" tests. The facts are that the results of all of the boiler performances recently presented by the U. S. Geological Survey which Prof. Breckenridge considers to be the best mass of data of the kind ever accumulated, are from tests of "coal" instead of tests of "boilers." There is absolutely no difference in the method of doing the work; it is exactly the same process, excepting that if the inquiry concerns the performance of a boiler it is called a "boiler test;" if it relates to coal, it is termed a "coal test," and these tests of Mr. Chauvet's on the Fisk Street boilers were all as carefully and accurately conducted as they could be, and would have been no different had their purpose been to accumulate information relative to the performance of the boiler or any other feature of the apparatus, and all the items it was possible to obtain as giving data for preparation of the heat balance was procured, with the exception of loss in the refuse which was very accurately determined by a large number of special tests made for that purpose.

Of all the discussion, that offered by Mr. Chauvet is the most valuable, because he concedes the accuracy of the test records upon which the consideration of the comparative value of the two boilers is based.

As already defined in the introduction to the paper, the object of the inquiry concerned only the matters of completeness of combustion and heat absorption, therefore it made no difference whether there was more loss of fuel in the ash pit in one case than in the other. This he ignores, confining attention exclusively to a comparison on a basis of fuel as *fed* instead of *burned*. His attitude is decidedly critical, and there can be no doubt that had he been able to discuss adversely the advantage of completeness of combustion and heat absorption shown by the improved boiler, he would have done so, but not finding this possible, he has advanced some very able and skillfully presented arguments regarding comparative performance on the basis of coal as fed, thus introducing the matter of stoker action which has no direct connection with the matter whatever. In addition he has persisted in ignoring the fact that the improved boiler No. 10 was entitled to be served with a gas as high in CO_2 as in the case of the other.

At the start his objections are summarized in three items, but it is well that the following sections numbered 1 to 8 have attention, and for identification the corresponding answers are given the same number used in his paragraphs.

1. 812 Horsepower for the Fisk Street boilers was not obtained

with Illinois Midland coal; it was from another group of tests than those giving the efficiency value, and it was employed because Mr. Chauvet, not the author, considered it representative for these boilers. The horse power as given in the last column of Table No. 3 indicates the average horse power of all of the tests made under boilers served by chimneys 250 feet high on coal from the seam mined by the Illinois Midland Coal Co.

2. Criticism of the diagram Fig. 6 is answered in the reply to Mr. McClure.

3. It is a fact that the CO_2 of 9.52 was not obtained at Cedar Rapids, but in justice to boiler No. 10 it ought to have been, thus it is entitled to credit for this reason.

4. If in applying the higher CO_2 to the improved boiler No. 10, a change has been made in the temperature of the flue gas, such change would have been a reduction, tending to increase efficiency, thus this criticism has no weight.

5. The comparison between Pawnee, Fulton County, Ill., and Iowa coal, is in no way significant, because the results are based on coal as *fed* and not as *burned* (gasified). It will also be observed that the comparative CO_2 is omitted. The efficiency and horsepower quoted for the Pawnee and Fulton County coal are based on a specific heat of 0.750 instead of 0.503, and no correction has been made for the difference in coal actually burned as compared to that charged to the stoker, features entirely distinct from that of loss in the refuse, which however of itself was much larger for the improved boiler. It did not serve Mr. Chauvet's purpose to base results on coal as burned, consequently he did not do so.

6. He states that the author claimed it necessary to waste large amounts of coal to prevent air leakage at the back of the grate, and in this connection mentions certain air dampers in the stoker, the inference being that these dampers would prevent leakage and that this waste of coal was unnecessary, yet in paragraph 3 he states that if the fire had not been run over the end of the grate as it was, CO_2 would have been even less than 7.6, two conflicting statements.

7. Regarding the comments relative to the unaccounted for loss, this is made clear by Mr. McClure's answer to Prof. Breckenridge's discussion. Mr. Chauvet is, however, very much in error in comparing the two cases of tile roof performance as one of them is fired by hand and the other by stoker, and he must be aware that it is impossible to obtain in intermittent hand firing a condition which will permit of complete combustion. That this is true is illustrated by Fig. 16 from "A Study of 400 Steaming Tests," page 151, issued by the U. S. Geological Survey, showing progess of unaccounted for loss with increasing incomplete combustion.

8. In taking into consideration the difference in the size of coal in the tests of the improved boiler and that at Fisk street, it so happened that the Illinois Midland coal used for the improved boiler was

of an unusualy favorable size, and if all other conditions in the two cases were equal, the improved No. 10 boiler would have shown a superiority in efficiency and capacity due to this better coal, but conditions differed, and notwithstanding the fact that this boiler was served with superior coal it did not attain as high CO_2 as Fisk

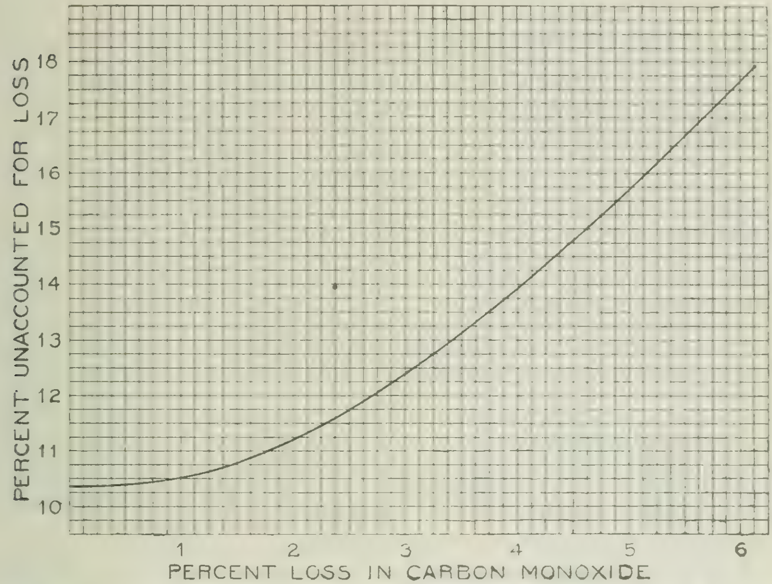

Fig. 16. Diagram showing progress in unaccounted for loss with increase of incomplete combustion. Page 151, A Study of 400 Steaming Tests, U. S. Geological Survey.

Street, for reasons which have been clearly stated heretofore, therefore the superiority in coal was not sufficient to place combustion on the same air supply basis as enjoyed by the Fisk Street boiler. These experiments to which Mr. Chauvet refers are valuable ones and it is fortunate that he cites them; also that he adds a corresponding CO_2 column, because it saves the author the trouble of extended explanation. The fact should be borne in mind that the size of the coal can have no direct influence on efficiency or capacity. It simply produces different condition of combustion, causing a higher or lower CO_2, and it is this condition of combustion which affects the efficiency and capacity, therefore if the better coal used under the improved boiler has produced a higher CO_2 than prevailed with the Fisk Street boiler, Mr. Chauvet's argument would have weight, otherwise it has not.

If stoker action could not be improved with boiler No. 10 then its advantage as compared with the Fisk Street boiler, except for smokelessness, would be small; but if served by as good a stoker, the performance of the entire apparatus on the basis of coal supplied, insures the same superiority as shown upon the basis of fuel

as burned. That this is true, is evidenced by the result of Mr. Greene's observations and experience which have enabled him to adjust the position of the water back and stop air leaks, so that he now obtains 15 to 17 per cent. CO_2 with a reasonable loss in the refuse.

Professor Breckenridge questions the accuracy of water meters, and states that his experience does not coincide with that of the author; in fact, that he has tried in several cases to justify the use of water meters, but the result has always been disappointing. He fails, however, to present evidence in form that would enable one to see for himself whether his "disappointment" necessarily proved that meters were unreliable. Had he made use of meters in good condition and kept track of their accuracy by sufficient amount of calibration, it would have enabled him to make much more certain and reliable water measurements than by any method of weighing or measuring in tanks, because by their use two important elements of uncertainty may be eliminated. One of these is error due to failure in properly recording quantities of water, which is often an almost physical impossibility when men have scarcely a moment's interval between tanks; the other is that of dishonesty in manipulation of records, two sources of error more common than many people suppose. With a meter, however, the engineers in charge may observe the indication at the start and finish of a test, in fact, the entire staff may do so. Thus two simple observations regarding which no question can be raised, is all there is to the matter. The requirements for successful water measurements by means of meters are:

1. A good meter.
2. Reliable calibration thereof.
3. Display of intelligence in the use of the device.

In reference to radiation losses, his disposition is to consider the amount larger than intimated in the author's paper, and estimates it at 3 per cent. but nullifies any advantage that should attach thereto by saying, "We have made at different times, numerous attempts to determine radiation losses from boiler settings, and the results have not been satisfactory." We would be justified in expecting more complete and authentic statement than this. Mr. R. S. Hale, who has made an extended study of boiler performance, has compiled a representative heat balance from data furnished by a large number of tests* as follows:

Lost in incomplete combustion of hydrocarbons......	7
Lost in incomplete combustion to carbon monoxid.....	1
Lost in sensible heat in flue gases....................	20
Lost in radiation..............................	1
Available in steam..............................	71
Total	100 per cent.

* Engineering Magazine, Vol. XVII, p. 626. Trans. Am. Soc. Mech. Engrs. Vol. XX, p. 769.

which supports neither Prof. Breckenridge's nor Mr. McGovney's arguments, when in respect to the latter it is considered that the greater portion of the tests used by Mr. Hale were with coal low in volatile matter, and for which reason, loss in escaping hydrocarbons is less than with high volatile coal as shown by Fig. 17.

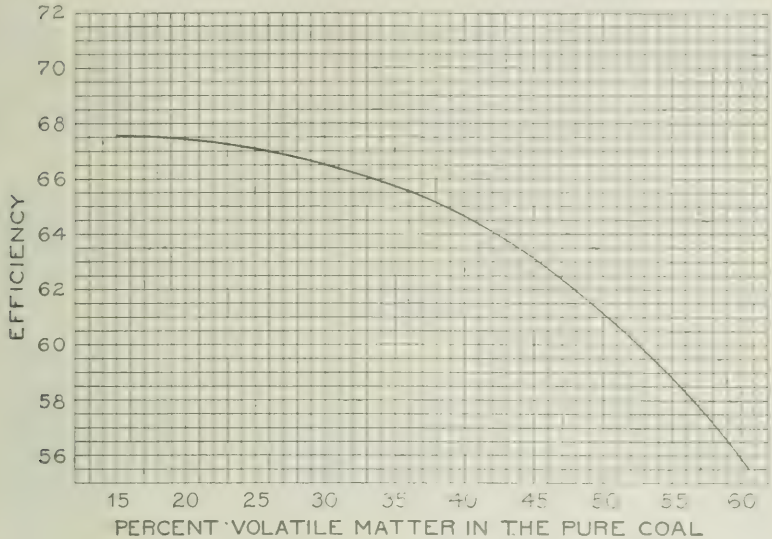

Fig. 17. Curve showing decrease in efficiency due to escaping hydrocarbons with increase of volatile matter in coal. Page 89, A Study of 400 Steaming Tests, U. S. Geological Survey.

Regarding the method of compilation of the comparative heat balance in Table No. 1, Prof. Breckenridge is incorrect in stating that the author is not justified in presenting the matter as he does, because the method consisted in adding together the known losses for the comparative conditions and subtracting the sum from 100, the remainder being the efficiency obtained by difference.

He has submitted a version of heat balance for Test No. 2, wherein more than 100 per cent. appears to be accounted for, even when radiation, loss by sensible heat in the refuse and moisture in the air are not included, which is offered as evidence that tests on boiler No. 10 are inaccurate. This conclusion he arrived at, apparently through an error, by assuming in calculating loss in the hot gases, that all of the fuel entered into the combustion process, as has been shown by Mr. McClure in a special discussion, when as a matter of fact some 15 per cent. of the coal entered the ash pit, therefore the weight of the dry gas which he took was approximately that much too large, with a corresponding effect on the heat loss calculated on such erroneous basis. This is a rather serious matter, and suggests the inquiry as

to whether the United States Geological Survey and Illinois Engineering Experiment Station tests have been calculated on such basis. If they have been, the unaccounted for loss reported in the U. S. Geological Survey tests is greater than supposed. It is an easy matter to fall into this error in calculating loss in hot gases, and it is possible that the code for boiler trials of the committee of the American Society of Mechanical Engineers is not sufficiently explicit to guard against it, and it is no doubt advisable that it be revised in this respect. Another feature might also have attention, that of hydrogen, as the code considers that air is supplied for all of it, when as a matter of fact only the available hydrogen combines with oxygen from the air, the remainder being already in effect in combination with oxygen in the coal.

Mr. McGovney thinks that there would be a "rose strewn path" for the tile roof furnace if it could burn up the unaccounted for loss. Aside from his horticultural simile it may be said that in this case the unaccounted for loss is a combustible one, therefore it is quite appropriate for the tile roof to burn it up.

He expresses interest in the author's method of making a comparison between the two boilers, and follows with the statement, "However, Professor Breckenridge has shown that the indications of such phenomena are due to erroneous methods in the calculations." The author, however, regrets that he is compelled to say that Prof. Breckenridge has shown something quite different from what Mr. McGovney has stated, as he will find in detail in the discussions prepared in answer by Mr. McClure.

He asks if experiments have shown 10.24 per cent loss due to smoke, apparently overlooking the fact that the determination of such loss was the main purpose of the investigation.

The thickness of fire or in other words, opening of the feed gate for tests represented by Fig. 6 and Table No. 2, being the same tests, was 7.73 inches.

The meaning of the latter portion of his discussion is not very clear, but the argument appears to be that the Fisk Street fires were not sufficiently thick for the draft used. The thickness employed was the result of study and experiment and is considered suitable for high capacity. At all events, the comparison between capacity of both boilers on the basis of draft at the chimney replies to the inference that the fires were not of proper thickness. In referring to the Engineering Experiment Station tests, he would have made his illustration much clearer had he stated what grade of coal was used.

If there is any question in his mind regarding the superiority in efficiency of the improved boiler, a comparison on the basis of coal reported as fed to the stokers should settle the matter, because such comparison does not require the use of a heat balance, the point he questions, nor does it take into account that the Fisk Street stoker used a better grade of coal than that charged against it.

	Improved Boiler Tests No. 3	No. 4	Fisk St. Boiler Average
CO_2	6.92	9.66	8.99
Per cent loss in refuse	6.71	5.68	2.41
Efficiency, reported on basis of moist coal as fed	66.07	68.20	64.91

Test No. 3 was made at the suggestion of Mr. Chauvet, who considered that tests 1 and 2 had not been conducted as well as they could have been and this one was superintended by him exclusively, the stoker being operated at his request by J. Murowski. The accuracy of the fourth test is certified to by Mr. Greene.

It is to be regretted that Mr. Bollinger did not see fit to state his experience with the Babcock & Wilcox boilers in the plant of the Western Electric Company, to which he has made an application of tile furnace roofs.

In Mr. McClure's answer to Prof. Breckenridge, concerning the matter of loss in hot gases, Mr. Pennock will find data which will show him that the total heat accounted for in test No. 2 is not above 100 per cent as he supposes.

Relative to the matter of moisture in steam, he considers that it ought to be not less than 1.5 or 2 per cent for the conditions under which the Cedar Rapids boiler was operated, but in this connection it should be said that there is no information bearing on the matter of moisture in steam which would justify his conclusion. Formerly, when manufacturers made guarantees, it was often stated that moisture would not exceed 1 per cent. Sometimes, however, determinations *appeared to indicate* that it was above this point, therefore it later became the practice in some cases to place it at 2 per cent, but as a matter of fact, the amount as obtained from the sample entering the calorimeter is no indication of the actual or possible quantity of water which may be carried out with the steam, and if anything, the higher the capacity the less indication of moisture there is in the calorimeter, but oftener reports have shown it as low as one-half of one per cent. An important contribution to this subject will be found in the Transactions of the American Society of Mechanical Engineers, Vol. XXVI, p. 312. Even if a calorimeter had been applied to the Cedar Rapids boiler, it would have in no way asisted the author in his presentation of the subject. It is a fact, however, that the B. & W. is a very dry steaming boiler, and it is well to call attention to this point, because Mr. Pennock's statement is inclined to convey the opposite impression.

It is probable, of course, that steam in contact with water contains some moisture, or is saturated as in the case of air or other gases, and if any water escapes in excess of this, it is because it is carried over mechanically. Thus there could be two conditions, one that of saturated steam which would be a natural state, in which it is as dry as it is possible for it to be without superheating, in other words,

"commercially dry steam;" or, as saturated steam which mechanically carries water with it. It is probable that if we know the per cent of natural saturation, account could be taken of it. As it is, however, the only thing a steam calorimeter has accomplished, is to cause confusion. Therefore, the author's assumption that steam was dry, leads to less error than would have been the case had an attempt been made to employ the indications of a calorimeter.

Analysis of the flue gas was made by a modified form of Orsat apparatus illustrated in the Journal of the American Chemical Society, Vol. XXVII, p. 1252.

The Keystone hot water meter used in the test of No. 10 boiler was certified to by the Pittsburg Meter Co., its maker, as being correct. During the test, the water which passed through it was first measured in calibrated tanks which afforded an opportunity to determine its accuracy. After the tests were completed the meter was sent to the Department of Public Works of Chicago and again calibrated, and the report of the Department stated it to be correct, therefore it should be said that as far as could be determined, the meter was absolutely accurate. Not only was every precaution taken to insure accuracy of the measurement of water as well as everything else, but evidence was obtained supporting the facts so there could be no question.

Professor Kent considers several important features. His criticism of the extension of the ignition arch so far into the furnace is excellent, and his prediction that it would burn out shows excellent judgment, because this is just what did happen to it. This long arch was the outcome of a suggestion made by Mr. Chauvet, and after it had been in use for something like two months, it failed by settling down

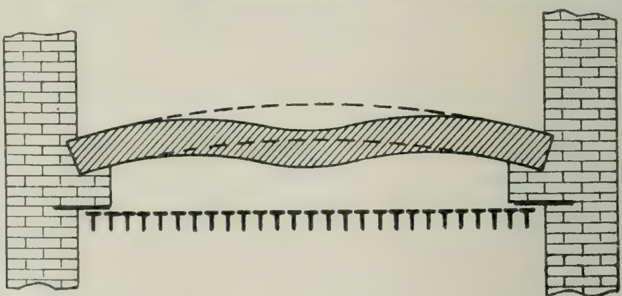

Fig. 18. Section showing manner of failure of long ignition arch.

in the center as shown by Fig. 18. There is really no occasion for such long arch, because corresponding effect may be obtained from the presence of the tile furnace roof.

In reply to the inquiry why such a high figure as 80.18 per cent efficiency has been employed in the preparation of Table No. 1 when the highest of the three tests in Table No. 3 is 66.07, it should be said that Table No. 1 was a compilation presented as an illustration show-

ing what the comparative performance would be if all of the coal fed was burned instead of a portion wasted in the ash pit, and this figure of course, should be much higher than any of those obtained in Table No. 3, because each of the tests had a very large loss by unburned coal which was discharged with the refuse. This matter, however, has been previously discussed in the author's closure.

In reference to the statement that the heat balance, Table No. 1, allows nothing for loss due to evaporating and superheating moisture in the coal, Mr. McClure's discussion of Prof. Breckenridge's conclusions treats of this matter in detail. The loss due to moisture in the air was neglected, or in other words, it was provided for in the item of heat unaccounted for.

It is a fact that the CO_2 for both of those chain grate plants under discussion was very low, and it is also true that with common eastern practice very much higher figures are easily obtained. The problem is a more difficult one with the character of coal that must be used in this locality as against that in the East. Western screenings contain a high percentage of dust and much ash. Since these tests were made, however, Mr. Greene has obtained a much better performance from this boiler by stopping the air leaks and reducing the opening between the water back and the end of the chain grate stoker, and reports that he now obtains CO_2 which easily ranges from 15 to 17 per cent.

In reference to Fig. 6, it is a fact that clinkering of coal would produce a condition indicated by this diagram. Such, however, would be more particularly true of forms other than chain grate stokers, with which such variations of draft are caused almost altogether by the size of the coal and quantity of the ash, although the latter does not to any great extent form compact clinkers.

Mr. McClure criticises the paper in a number of respects. The title first has attention, and it is his argument that the apparatus shown in Fig. 1 should not be considered as an improved boiler *per se,* but that it is an improved Babcock & Wilcox form. The author, however, cannot agree with him, because the design has not received the sanction of the builder of the B. & W. boiler, and it is not recommended by that Company, which claimed no responsibility for its successful working, nor in any way assumed or endeavored to assume proprietorship in the design. The fact that it has 3½ inch tubes in the bottom row, in addition to the reversed travel of gases and presence of the tile roof, are features which have never received endorsement from the maker of this type of boiler, therefore it is felt that it should more properly be considered a new design which copies the better features of the B. & W. apparatus rather than being an improvement of that boiler.

He, like Messrs. Brydon and Chauvet, criticises diagram No. 6 and asks, for further explanation, therefore Fig. 10 is submitted*

*Journal W. S. E. Vol. IX, p. 44.

which it is trusted will make the matter clear. The diagram is from experiments with a chain grate stoker and Babcock & Wilcox boiler using fairly uniform coal in different tests, with varying strength of draft, and it would appear therefrom, that there is sufficient justification for the use of Fig. 6. It will be observed that the curve of efficiency assists materially in locating the point of zero capacity.

Mr. Greene asks what advantages are claimed for the setting shown by Fig. 5 over that in Fig. 1. The author regrets that he is unable to furnish reply to this inquiry.

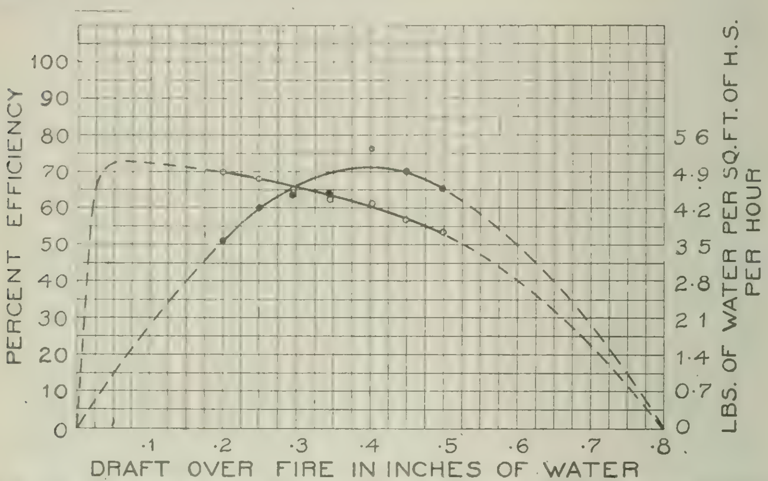

Fig. 16. Diagram showing capacity and efficiency with varying strength of draft with Babcock & Wilcox boiler and chain grate stoker.

Mr. Kershaw has rendered excellent service in presenting the experience of himself and associates in Great Britain. His observations have been extended, consequently his opinion is authoritative, and the author wishes especially to thank him.

In reply to the question regarding the cost and maintenance of the tile roof,—the tiles are one foot long, two being required to cover each foot in length of boiler tube. The cost of the tiles has been from 10 to 12 cts. (5 to 6 d.) each, and their average life is from one to two years. They may be put in place by the men who ordinarily care for boilers, the services of a brick mason not being required.

Mr. Abbott gives the pounds of water evaporated per pound of combustible (pure coal) burned (gasified) for the Babcock & Wilcox boiler as 9.67; this, however, is based on a loss of 2.67 per cent in the refuse, and it becomes 9.64 when final correction due to ultimate analysis of refuse is made, which gives a refuse loss of 2.41 per cent instead of 2.67, therefore the correct comparison is 9.64 as against 10.47 in tests 1, 2 and 3, of the improved boiler, and this does not take into account that the Fisk Street boiler used coal superior to that charged against it, as mentioned in the explanation to Table No. 3.

Mr. Scholz does well in calling attention to the fact that at present, our most serious smoke problem is in connection with return tubular boilers. This is true because it has been thus far assumed that smokeless results were to be obtained from this class of apparatus by means of careful firing, or in other words, a uniform feed of fuel such as obtained with a stoker. The fact, however, should be taken into consideration, that it is impracticable and often impossible to obtain the necessary uniformity in feed of coal, and that any remedy for these cases must be sufficiently comprehensive to overcome the effect of this condition of irregular feed.

Mr. Kuss has suggested that detailed data for the Fisk Street Station tests be inserted, which has been done in the enlarged Table No. 3. The author, however, is not certain that its presence would have reduced the amount of adverse criticism. If so, the author is glad that the data was not inserted, in view of the fact that sufficient information for all necessary purposes was presented in the appendix.

Mr. Williams has shown views of two designs of boiler submitted to him when bids were asked for boilers at Cedar Rapids, and the author will explain that both Babcock & Wilcox and Heine types were prepared in two forms, one having five passes of the gases across the tube surface and the other three passes, for the reason that at that time it was not decided whether or not it would be desirable to employ a three or five pass boiler.

Mr. Harrington is right in considering that the advantage of smokelessness and complete combustion are due entirely to the better provision for burning the coal, because as far as the boilers themselves are concerned, it is no doubt true that the standard boiler in itself is as efficient as the improved one.

It is unfortunate, however, that Mr. Harrington does not believe there is necessity for this particular form of furnace. It would be possible, of course, to obtain equally complete combustion without such furnace roof and with vertical pass boilers, provided the boilers are set sufficiently high above the fire, but to obtain such conditions would require enormously high settings, and it is more economical and satisfactory to obtain the same effect by length of travel horizontally in the space below the boiler, which can be readily done.

Mr. Boegershausen asks whether the tile roof is an absolute necessity in the prevention of smoke, and it is probably best to reply that it is essential for all stoker conditions, chain grates included. In the case of an application of chain grates to Heine boilers with the usual lower baffling made of T tiles, which expose the entire lower half of the bottom row of tubes of the boiler, there issued a persitsent and continuous volume of smoke in serious amount, although not black in color. The application in these cases of encircling tiles to the lower row of tubes eliminated this smoke.

To Mr. McDonald I would reply that it is not stated in the paper that the design presented by Fig. 1 will give better results than that shown by Fig. 5. In fact this is not considered. The comparisons drawn between the two were simply confined to the mechanical features of the setting, such as height, etc. Mr. Greene, however, in his discussion intimates that radiation would be so high on account of the much greater exposure of the furnace walls, as to reduce efficiency in considerable measure.

Mr. McDonald states that best practice favors that the hotter gases be in contact with that portion of the tubes which contain the "hottest" water. His argument appears to be that the common setting of the Babcock & Wilcox boiler shown by Fig. 2 and the design Fig. 5, complies with this, and such conclusion appears to be arrived at by him because the heat first impinges upon the high end of the tubes where with boiler No. 10 it first comes in contact with the low end. His reasoning, however, is upon the assumption that the temperature of the water increases after entering the tube, so that at its exit it is greater than at the entrance. This is a more or less common assumption on the part of many people, based upon the belief that the water accumulates heat which is liberated in the form of steam when the water line surface in the drum is reached. The facts, are, however, that the temperature of the water is that due to the pressure under which the boiler operates, and that such temperature is uniform throughout the entire space, and instead of the water accumulating heat to be liberated as above indicated, steam forms immediately at the point of heat application and passes along with the water to the drum; thus instead of the temperature of the water being increased by the application of heat, a portion of it is turned into steam at the moment, therefore it must necessarily follow that the temperature is the same at both the higher and lower end of the tubes and that there is no such condition as Mr. McDonald believes to exist.

A FEW UNUSUAL BURN-OUTS OF UNDERGROUND CABLES.

D. W. Roper, m.w.s.e.

Presented, December 13, 1907.

The average burn-out of underground cable possesses little individual interest, and becomes interesting only when tabulated with many other similar burn-outs to show the experience of several years. There are, however, occasional burn-outs which in some manner cause break downs of other cables or apparatus that far exceeds the damage due to the original burn-out. A rare case of this kind, notable for the great damage done as well as for the very complete mathematical analysis which it received, was described by Mr. Steinmetz in a paper read before the A. I. E. E. in 1905. The arc, at the point where the cable burned out, started a surge that caused internal strains in the electrical system, and broke down a number of cables as well as several of the generators in the power station.

There is another class of cable troubles where the arc at the point of break down, or the current flowing to the lead sheath through the arc, injures the lead sheath of other cables at adjacent or distant points, so that they either break down, or are rendered unfit for further service. All the cases to be described in this paper belong to this class. It generally happens that these cases which involved more than one cable are most difficult to diagnose. It is only by a careful comparison and analysis of all of the facts and the conditions existing at the time that the sequence of events can be determined. After this is done the cause, or at least the location, of the original fault is easily determined. Such an analysis is of value to those who install and operate cables, as it demonstrates what are the vulnerable points of the cable system, and therefore, shows what features of installation or operation are to be eliminated and avoided.

In each of the three cases to be considered, the location of trouble was rendered impossible by electrical methods, as all of the conductors of the cable were either entirely burn in two or were grounded; that is, there was no good conductor which could be utilized in a loop test. In only one of the cases, however, did we have to resort to the "cut and try" method.

The first burn-out is the only one of the three to be considered in which the original cause of the trouble is definitely known. Shortly before this burn-out occurred, arrangements were being made to test one of the high tension buses at the Fisk St. Station. In doing so one of the testing leads, consisting of about 50 feet of No. 6 wire, was accidently connected between one phase of the live high tension bus and the ground bus. One phase of the system was thereby short circuited through this wire. The short circuit entirely vaporized the copper of the testing lead, but did very little other

local damage. A few seconds later the oil switch on line No. 101 opened, and a test showed that all three conductors of the cable were grounded. The automatic devices on the oil switch were slow to act, so that the interval between the breaking down of the cable and the opening of the switch, appeared to be about two or three times the normal amount; that is, the short circuit due to the cable burning out lasted between three and six seconds, instead of the usual one and one-half or two seconds. The following table gives information regarding the line and the operating condition at the time of the burn-out:

Total length of line	18,390 ft.
Distance from station to point of burn-out	4,600 ft.
Load	9,200 kw.
Voltage on buses	9,100 volts.
Turbines in operation, 1—5,000 kw. and 1—8,000 kw.	
Converting apparatus in operation	17,000 kw.
Converting apparatus automatically disconnected	11,500 kw.

The operator at the Fisk Street Station reported afterward that, as near as he could recall from a hurried glance at the instruments, the frequency dropped from 25 to 20 cycles as a minimum, and the voltage dropped from about 9.100 to a point between 5,000 and 6,000 volts.

After some difficulty, the burn-out on the cable was located on Morgan street in the conduit section south of 16th strret. The cable was withdrawn in two sections showing that the location of the burn-out was 50 ft. south of the manhole at 16th street. In Fig. 1, is shown about 10 ft. of cable from each of the two ends adjacent to the burn-out. It will be noted that there are several places along

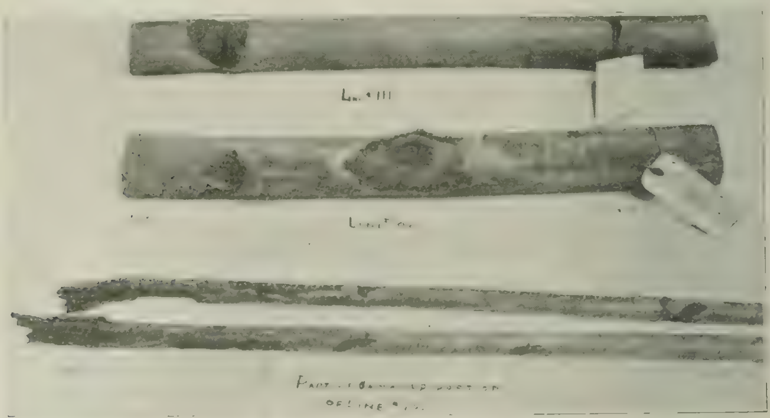

Fig. 1

the cable where the arc, in traveling along the duct, has burned holes entirely through the lead. Similar holes were found up to a distance of about 20 ft. from the ends of the cable. No accurate measurements were made at the time which would enable us to determine the distance between the two ends of the cable after the burn-out, but it is estimated at about one foot As soon as the burned cable was withdrawn, the duct was rodded without difficulty, and a new section of cable drawn into the duct, and connected to the adjacent sections.

Holes were also found in the lead sleeves over the cable joints in adjacent manholes where they rested in iron brackets or shelves. There were caused by the current from the arc traveling along the lead and passing through these brackets to ground. This is readily accounted for by the fact that, at the instant of break-down, the lead at the point of burn-out may be several thousand volts above ground potential. After these holes were repaired and the section of cable south of 16th st. had been replaced, the line was tested and placed in service. The incident then appeared to be closed.

A careful examination of the burned ends of the cable, and a consideration of all of the circumstances at the time of the burn-out, especially the duration of the arc, and the drop in speed and voltage of the turbine due to the energy in the burn-out, indicated that an enormous amount of energy was expended in the arc. As the conduit in which the burn-out took place contained cables which carried one-third of the total output of the Fisk St. Station, it was decided to dig up the street at the point of the burn-out, break away the conduit and tile, so as to expose the interior of the tile which enclosed the burned-out cable and ascertain what damage, if any, had resulted to the conduit and the adjacent cables. To make this examination we selected a Sunday morning ten days after the burn-out, at a time when the load was so light that the other lines on the same side of the conduit could be taken out of service. The conduit at this point contains twenty-five ducts, arranged as shown in Fig. 2, which also indicates the location of the fifteen, 9,000 volt, three-conductor cables in service at the time of the burn-out.

The effect of the arc on the conduit and cables as determined by this examination is indicated roughly in Fig. 3. The heavily shaded portion of the ducts and the cable indicates the part which was burned away at the point where the most damage was done. The appearance of the conduit and cable indicated that the arc, for a distance of several feet entirely filled the duct, and burned completely through the tile in two places on opposite sides of the duct, and permeated into all of the crevices of the conduit structure immediately adjacent. On one side the arc burned through the tile and extended into the concrete about two inches. It also burned through the duct at the upper inner corner and then entering the triangular void left between the tile as indicated, traveled along in this space and entered the ducts enclosing lines No's. 102, 103 and 111 through the joints

at the ends of the tile. It also burned entirely through the tile surrounding line No. 102 at a point opposite the joint in the duct enclosing line No. 101. The cable of line No. 103 had only a small hole in the lead sheath which was readily repaired by patching. The cables of lines No's. 102 and 111 were burned entirely through the outer layer of insulation, and approximately half way through the inner layer of insulation, as shown by the photograph in Fig. 1. These two pieces of cable were withdrawn and replaced by new cable.

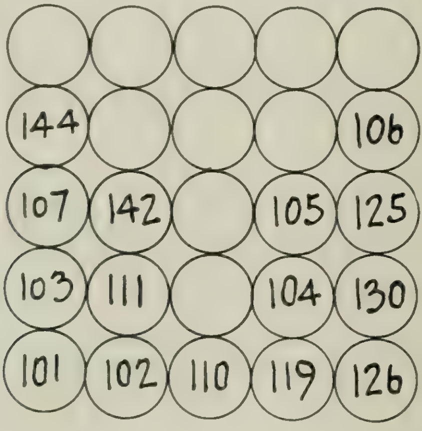

FIG. 2

16TH & MORGAN - DIAGRAM OF

CONDUIT SHOWING CABLES IN SERVICE

The later style of square tile with rounded corners leaves a much smaller void in the conduit as shown in Fig. 4. This would probably have reduced the injury to other cables in adjacent ducts.

The thinness of the tile immediately surrounding the arc indicated that the tile must have been heated to a temperature which vaporized the tile and carried it away in the currents of air. There were no signs of any melted tile found in the duct. Although very badly burned, the duct was still in such a condition that the burned out cable of line No. 101 was readily withdrawn and replaced by a new section, which was in place at the time that the physical examination of the conduit was made. The intense heat at this point and its remarkable effects on the conduit and adjoining cables suggest an inquiry into the amount of energy expended in the arc.

The field characteristics of the machines show that the maximum output of the two machines would be about 8500 kw. per phase, or approximately 25,000 kw. total. This maximum output would cor-

respond to about 6000 volts between terminals with about five ohms external resistance in each of the three phases. We know from theoretical considerations as well as from the ocillograph and from examination of machines that have been suddenly short circuited, that the current flowing at the instant of short circuit, would be many times that obtained by gradually reducing the resistance in the armature circuit to zero. With the adjustment of the automatic ap-

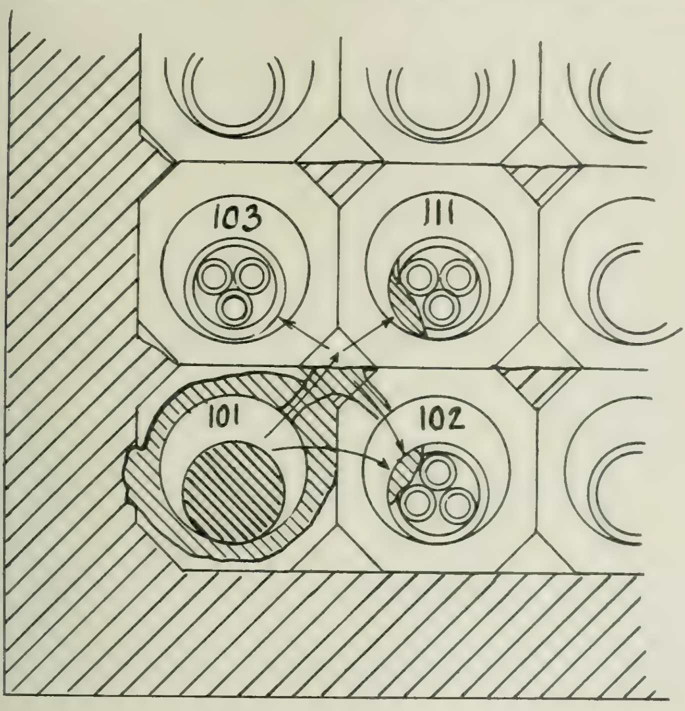

FIG. 3

16TH & MORGAN - SECTION SHOWING COURSE OF ARC AT TIME OF BURNOUT

paratus existing at that time, nearly two seconds would normally elapse between the instant of the break and the instant of the opening of the oil switch. The operators all testified that the duration of the burn-out was in this case two or three times the usual period. If the output of the two turbine generators averaged 25,000 kw. for four seconds, this would correspond to an output of 100,000 kw. sec. or about 29 kw. hrs. This figure would be somewhat larger, say 35 kw. hrs. if proper allowance could be made for the enormous cur-

rent at the instant of the short circuit. As the resistance of the copper to the point of the burn-out was about 0.23 ohms., and the total resistance per phase corresponding to the above output is about five ohms, indicating that about 95% of the energy was in the arc.

As a rough check on this figure, we can determine the loss of inertia of the two turbines corresponding to the drop in speed from 25 to

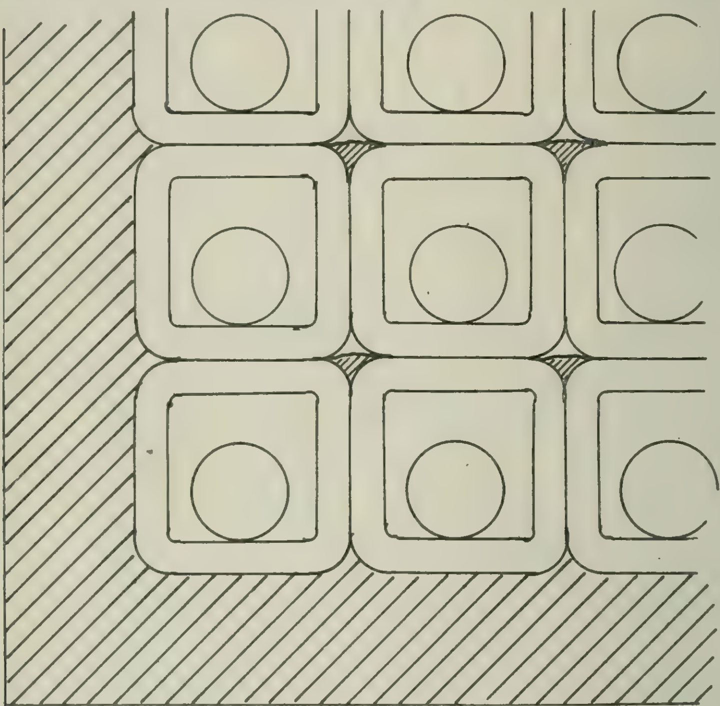

FIG. 4

16TH & MORGAN - SECTION SHOWING REDUCED VOIDS IN CONDUIT WITH SQUARE TILE

20 cycles. The moment of inertia of the larger turbine is about 44 kw. hr., and of the smaller turbine about 32 kw. hr., or a total of 76 kw. hr. As the moment of inertia is proportional to the square of the speed, and the loss of inertia corresponding to a drop from 25 to 20 cycles (or from full speed to eight-tenths of full speed) would be thirty-six per cent. of the total or about 27 kw. hrs. The action of this additional load on the turbine would cause the govenors to

admit more steam, probably up to the maximum capacity of all the nozzles. The steam opening at the beginning of the trouble corresponded to the load at that time, i. e. 9200 kw. At the end of the trouble the nozzle valves were probably admitting steam corresponding to an output of about 20,000 kw. If we assume then the steam supply averaged 15,000 kw. for four seconds, the output during this period would be 60,000 kw. sec. or 17 kw. hrs. In addition we know that all of the converting apparatus was suddenly reduced in speed along with the turbines, so that they sent current backward toward the station. Assuming that this backward flow of current from the converting apparatus was on the average equal to the rated capacity of the apparatus for a period of one second, this figure would be 18,000 kw. sec. or 5 kw. hrs. The summary of the loss of energy during the period of the burn-out would then be:

Loss of inertia of turbines	27 kw. hrs.
Steam Supply	17 kw. hrs.
Backward flow from converting apparatus	5 kw. hrs.
Total	49 kw. hrs.

This figure is to be compared with 35 or 40 kw. hr. which was estimated as the maximum output of the generators during the period of the burn-out, and agrees within the probable errors of observation.

We can then assume, with a fair degree of approximation, that the energy in the arc averaged about 20,000 or 25,000 kw. for several seconds; or expressed in other units, the dissipation of heat was between 18,000 and 22,000 B. t. u. per second for a period of several seconds.

If we figure the weight of the various portions of the cable and their specific heats, we will find that energy in one kilowatt hour is sufficient to raise the temperature of one foot of cable about 5000 deg. C. This is probably above the temperature of vaporization of lead and copper. As the other calculations show that approximately 20 or 30 kw. hr. were dissipated in the arc it is easy to understand why several feet of the cable, as well as several pounds of clay tile entirely disappeared.

No pretensions of absolute accuracy are made for the above figures. Their only object is to determine roughly the rate of dissipation of energy, that is of heat, in order to account for the extent of damage done and to enable comparison with other similar cases.

For comparison with these figures, it might be mentioned that in case of the burn-out described by Mr. Steinmetz, as mentioned above, the capacity of the generators connected to the buses was about three times that of the generators in this instance, and Mr. Steinmetz estimated the maximum energy in the arc to be about 100,000 kw.

We can summarize regarding this burn-out as follows:

The break down was due to a surge in the system caused by the accidental short-circuiting of one phase of the system. About 25,-

000 kw. of energy was dissipated in the arc for about four seconds which generated sufficient heat to vaporize a portion of the enclosing duct and adjacent ducts so that the arc burned the lead off of cables in adjacent ducts.

Some of the lessons from this case are, the importance of limiting the flow of energy at the time that a cable burns out, and of building conduits and protecting cables so as to prevent an arc in one duct from communicating to another.

The second burn-out to be considered included 500 volt as well as 9,000 volt cables and was one of the most extensive burn-outs in the history of the company. Not only was it very difficult to find the cause of the burn-out, and to explain why such an enormous amount of damage was done, but locating the trouble itself for a while baffled all attempts. It was possible to solve the problem of locating the trouble and of accounting for the damage done only by a close study and comparison of all the events which occurred at the time of the burn-out and subsequently. For this reason and on account of many unusual circumstances, these events will be related in considerable detail.

The switch on line No. 140 opened automatically at 6:10 p. m., indicating the line had burned out, followed 25 minutes later by the switch on line No. 132. These two lines and one other similar 9,000 volt, three-conductor cable extend in the same conduit from our Fisk St. Station along 22nd St., 23rd St., 40th Ave. and the alley south of Harrison St., to 45th Court, where two of them enter a sub-station. The other line continues westward for several miles to a sub-station in Oak Park. A preliminary test showed that all three conductors of both of these cables were grounded. The test also developed the further alarming symptom that the cables were apparently crossed with a 500 volt circuit. These two 9,000 volt lines which burned out are entirely underground, and the only place where there is a 500 volt cable in the same conduit with them is on 40th Ave., between the alley south of Harrison St. and 21st St. The 500 volt cable extends between the the Metropolitan W. S. elevated railway structures at these two locations. For about half of this distance there are two separate conduits entering the same set of manholes. The 500 volt cable is in this portion trained on the opposite side of the manholes from the 9,000 volt cables; for the remaining distance, or about one mile, the cables are in the same conduit, and were trained on the same side of all the manholes as the burned out 9,000 volt cables. Fig. 5 shows the arrangement of ducts and cables in this conduit. Each manhole along this portion of the route was opened and carefully examined. The 500 volt cable was taken out of service during this period. Absolutely no indication of the trouble was found in any of the manholes, and as the cables were not adjacent to a 500 volt circuit in any other portion of their course, except in the railway sub-stations themselves, the searching party retired shortly after midnight in a very puzzled frame of mind. The

500 volt cable was again placed in service and so remained till the middle of the following afternoon.

Next morning another party started to go out over the rest of the line and see if any signs of trouble could be located. At this time another test failed to indicate any cross with the 500 vole circuit. One of the lines was about ten miles long and the other seven miles so that it did not appear desirable to begin trying to locate the trouble by the "cut and try," method until all other means had been

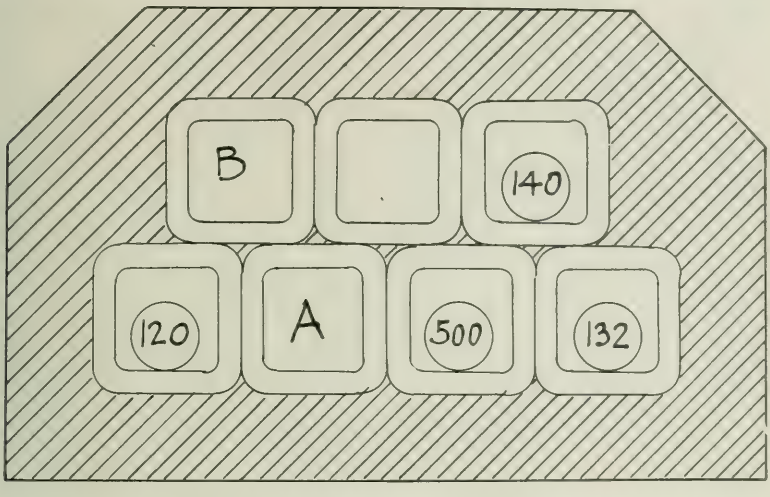

FIG. 5

40TH AVE. N. OF 18TH ST.

SECTION OF CONDUIT

exhausted. It was reported that a manhole cover had been blown off by an explosion on 40th Ave., south of 16th St. The men sent out to replace the cover found a stream of water running into the manhole from one of the ducts. This manhole had been opened between 11:00 and 12:co the previous evening and the cover carefully replaced. A woman living in a building opposite this manhole reported hearing a gang of men working in the street late the previous night and of hearing an explosion at the same place some time afterward in the middle of the night. Our men also found that the 500 volt cable in this manhole as well as in the next manhole north was quite warm. By cutting one of the cables in this manhole and in the next manhole towards Fisk Street, which was at 18th Street and 40th Ave. it was found that the trouble was between these two points. On attempting to pull out the cable through the manhole at the alley south of 16th Street we secured a piece only 50 ft. long. The distance between these two manholes was about 500 ft. We

then attempted to pull the remainder of the cable from manhole at 18th Street and secured a piece about 200 ft. long. This left about 250 ft. of cable in the ground. As the ends of the pieces removed were very badly burned, and as the only possible way of removing the 250 ft. of cable still in the duct was to dig up the conduit and secure the two ends, we immediately started two test pits about 10 ft. long at each end of the piece of cable which remained in the ground. The temperature at this time was ranging between 10 and 15 degrees Fahrenheit, so that the ground was frozen solidly to a depth of about eighteen inches. This made the work of excavation very difficult, but the gang digging the hole to the north found that the ground was not frozen quite as deeply as at the point to the south. As they proceeded deeper they found that the earth was steaming when exposed, and later they threw out dirt which was at a temperature considerably above blood heat. The opening to the north also exposed a broken water service, which accounted for the water running into the manhole 50 ft. north of this point.

An examination of the injured cables showed that they were in a number of pieces in this distance of 250 ft., so that it was impossible to clean out the ducts without removing them. The duct marked "A" in Fig. 5 was filled with lamp black, so that it would have been very dificult, if not impossible, to clean it out. This lamp black was probably caused by vaporization of the resinous compound in the burning cables, which, passing through the joints between ducts, deposited in the cooler adjacent duct. This duct, therefore, had to be removed, and the duct above it was broken out in doing this.

For a distance of about 10 ft. adjacent to the broken water service, the duct marked "A" was filled with a substance resembling sealing wax, in which was found occasional pieces of concrete. The bottom of this duct, as also the one surrounding the 500 volt cable was melted out and the melted tile had penetrated into the concrete and badly burned it for about half of its depth. The duct "A" also was filled with the melted tile to a depth of two inches for about ten feet in length. The temperature of this material was so high that it injured the walls of the duct marked "A," and also of the duct enclosing line No. 120, so that this latter duct fell away in places when duct "A" was removed. In so doing it exposed the cable of line No. 120. As this line was in service, and was the only remaining line to feed the Metropolitan L. Substation at 45th Court, we were a little anxious about its condition. A little careful probing with a stick through the opening in the tile showed that the lead had been burned off of this cable on the side towards the injured ducts for a distance of about two or three feet, the maximum width of the opening being about 0.5 inch. All of the ducts except the one enclosing this line had now been broken out for a distance ranging from two or three feet up to 250 ft. and there remained no complete duct in which a cable could be installed. It was, therefore,

necessary to shut down for about four hours the sub-station fed by this line, so that another cable could be installed in an adjacent duct. After this was done, split tile was placed around the cable where the duct had been broken out and the work of replacing the rest of the conduit proceeded.

After the 500 volt cable in this block was disconnected from the rest of the cable it was found that the portion toward the north showed signs of a ground. This did not appear to be a metallic ground but when the insulation was tested in the ordinary manner with 500 volt current and a bank of five lamps in series, the resistance was sufficiently low to allow the lamps to burn nearly to full candle power. The trouble was finally located in the block of conduit extending from the alley north of 12th Stret to the alley south of 12 Street. In withdrawing this piece of cable from the duct it was found that the lead sheath for a distance of about 100 ft. in the middle of the length, was eaten through in rings around the cable located 18 inches apart. The tile which are used in this conduit are 18 inches long, so that these rings where the lead sheath of the cable were eaten away were undoubtedly at points opposite the joints in the tile. The condition of this cable in this injured portion showed that the conduit in the middle of the section between the manholes was lower than the rest and was full of water. The cause of the trouble at this point will be more apparent when the cause and nature of the trouble at the burn-out north of 18th St. is examined in detail.

What probably happened is as follows: The 500 volt cable broke down at a point about 200 ft. north of 18th St. The exact cause of the break down of this cable in the conduit is not known, but other similar cables have broken down without apparent cause so that it is not an unreasonable supposition in this case. As indicated in Fig. 6 the lead sheath of this cable was not connected to the lead sheath of the other cable at any point south of the burn-out, and there was an insulating joint in the lead sheath of cable at the point where it extended up through an iron pipe to the third rail on the elevated structure. The potential of the elevated structure at 21st St. was, at times, about 50 volts above that at Harrison St., and the insulating joint was installed to prevent the lead sheath of this cable acting as a negative return to the railway current. The lead sheath of this cable was, however, connected to the lead sheath of the 9000 volt cables at the alley south of Harrison St., and these latter were again connected to each other and to the elevated structure at a point oposite the sub-station near 46th Ave. The current from the burn-out, therefore, in order to complete the circuit had to travel north along the lead sheath of the 500 volt cable on 40th Ave. to the alley south of Harrison St., and then divided among the lead sheaths of the three 9000 volt cables, extending to 45th Court, and there through a No. 00 wire to the elevated structure. The total resistance of this return circuit was about 0.7 ohms, so that if there

was no resistance in the arc at the point of burn-out, the maximum total current would be about 800 amperes. There was probably at all times a resistance of several ohms in the arc itself, so that the cur-

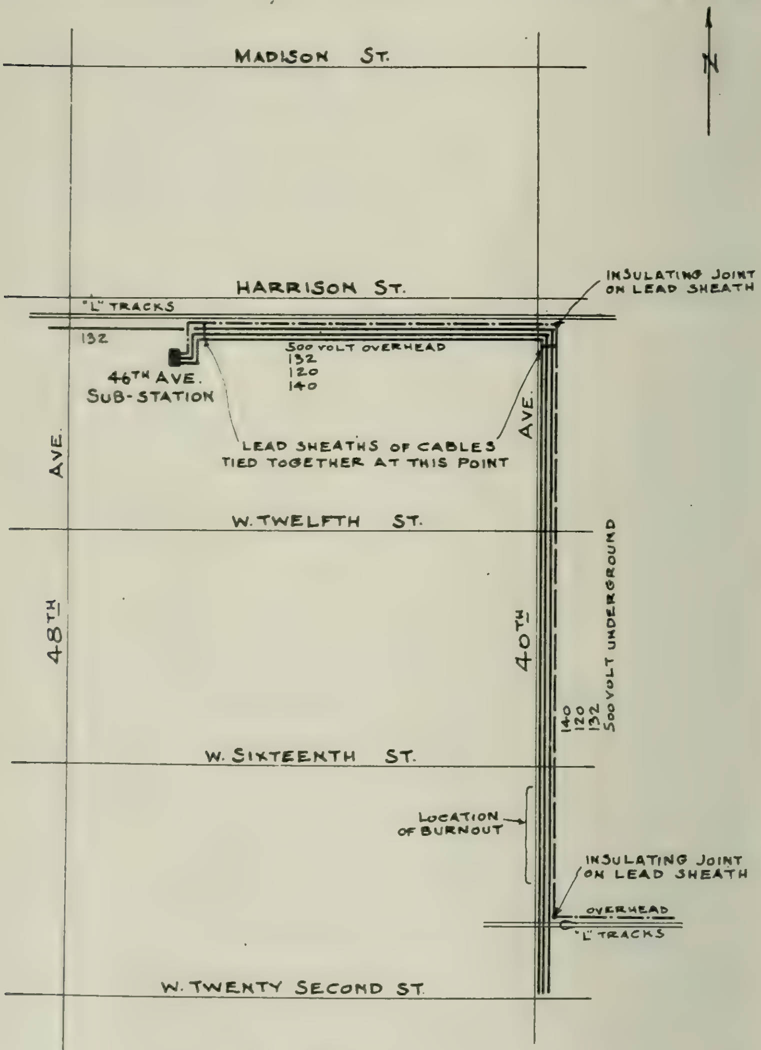

FIG. 6
DIAGRAM SHOWING CONNECTIONS OF CABLES ON 40TH AVE.

rent which returned through the lead sheath over the path indicated was probably never more than two or three hundred amperes. This is further corroborated by an examination of a No. 00 ground wire,

which showed no signs whatever of any overheating. The small possible value of the current also accounts for the circuit breaker at the sub-station remaining closed throughout the trouble.

There was a burn in the conduit a few fet north of the extreme south end of the burned cable. The places where the conduit showed evidence of greatest heat were two in number, one being the one above mentioned where the tile was melted near the north end of the burnt section of conduit, and the other for a short distance near the south end of the burnt conduit. In the former case there was a lead water service pipe embedded in the conduit structure, and the current from the burn-out must have returned to the negative bus at the sub-station through this water service pipe. The higher temperature at these two points was undoubtedly due to the large amount of current returning to the negative bus at the sub-station through these water service pipes. This path, being a considerable lower resistance than the other one, allowed a greater amount of current to flow and caused a more severe burning than in the portions where it did not reach the water pipes. The indications are that the current did not return through these pipes, except when the arc from the injured cable was in the immediate vicinity.

The explosion which blew off the manhole cover at the alley south of 16th St., and which was heard by the woman in the adjoining house, was undoubtedly caused by the water from the injured water pipe near the north end of the conduit coming into contact with the molten metal and tile.

If we assume that a current of 200 amperes was flowing in the return circuit through the lead sheaths of the cables, this would correspond to about 400 volts drop in the arc, and the lead sheath of the cable at 12th St. would then be about 40 volts above that of the negative bus. The conditions at 12th St. are shown in Fig. 7. There is a catch basin adjacent to the conduit south of the intersection at 12th St. and a water shut-off just north of the intersection. Both of these were partially filled with water. The deep conduit at this point was due to obstructions which were found in the street at the intersection and the water probably leaked into the conduit from the catch basin and from the water shut off. As the lead sheath of this cable was approximately 40 volts above the adjacent street car rails the current left the sheath at the points opposite the joints in the tile, and then traveled through the dirty water in the ducts and concrete and through the moist adjacent earth to the street car rails. The resistance of this return circuit had probably been somewhat lowered by the practice of the street car employees in salting the rails at the intersections and crossings. The rings around the lead sheath cable where the lead was missing were, therefore, caused by a very violent electrolysis of the lead due to the action of the current from the burn-out leaving the lead sheath at these points.

In order to corroborate this theory as well as to determine the condition of the other cables in the same conduit, the 9000 volt cables

were disconnected, one at a time in this block, and drawn slowly through the manhole into the next section of conduit. Upon examining the cable as it passed through the manhole similar indications of electrolysis were found on these two cables, especially on the two which were in the ducts adjacent to the 500 volt cable. The lead had not been eaten to an extent which warranted the replacing of any of these sections, and the sections of cable were drawn back into their proper positions and reconnected. These pieces of cable are still in service.

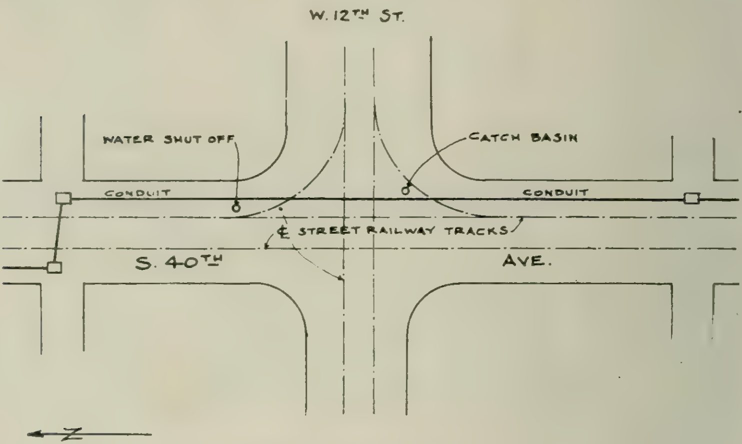

FIG. 7

DIAGRAM SHOWING CONDITIONS AT S. 40TH & W. 12TH

The 500 volt cable referred to was a concentric cable similar to that which is used for low tension feeders, each of the conductors being of 1,000,000 c. m. cross-section. For a considerable distance in the section where the cables were burned, it was found that the outer conductor of the lead had entirely burned off, or so badly burned, that it dropped away leaving the inner conductor bare, but uninjured. There was a total of about eleven tons of junk and lead removed from the conduits in the two locations, of which less than two tons was in condition so that it could be used again in other places.

The first indication of the third series of burn-outs occurred at 10:31 p. m., when the switch on line No. 128 opened automatically at the Fisk St. Station. About 50 minutes later, or at 11:20 p. m. line No. 133 opened automatically; at the same time considerable oil was thrown violently out of the oil switch, injuring the insulators and doors. This was followed six minutes later by the opening of line No. 164. Two other cables on the same side of the tunnel broke down under a high tension test shortly afterward.

The trouble was located with comparatively little difficulty in the east side of the Quarry St. tunnel. This tunnel extends from a point adjacent to the Fisk St. Station under the south branch of the river to a point near the north end of Quarry St.

On account of some changes in progress at the time we had sufficeit spare cable on the other side of the tunnel, so that all of the

Fig. 8

important lines could be temporarily transferred to these spare cables. The tunnel was then pumped out, and the conditions as shown in Fig. 8 were found. In addition to the burn-outs shown on this picture, line No. 128 was found to be burned nearly in two at a point in the tunnel about 120 ft. from the north shaft.

A careful investigation and comparison of all of the facts in the

case show that the sequence of events was as follows: Line No. 128 burned out in the conduit in the tunnel; two of the conductors burning entirely in two. The current from the arc traveling along the lead sheath of the cable to the bottom of the south shaft burned the lead of this cable, and also of the cable of line No. 164 where one cable laid across the other. The current was sufficient to melt the lead off of both cables so that there was no longer any metallic contact, and then continued to arc across the gap between the lead sheaths of the two cables. The action of this arc, which was 35 ft. under water, was similar to an explosion of dynamite. The gases generated by the arc had sufficient pressure to drive the water back in all directions to a sufficient distance so that the arc burned holes in the lead sheath of adjacent cables. All of this took place in about 2 secons or less. The water gradually penetrated the paper insulation of line No. 133 so that after 50 minutes the cable broke down. All three conductors, as well as the lead, were burned entirely in two, with a clear gap of about 3 inches. In a few minutes line No. 164 broke down in a similar manner, but the arc was between a single conductor and ground.

The burn-out of line No. 133 was about as severe as any that we have had, judging by the action of the oil switch. The hole burned in No. 164 is about as small as we ever find. The principal difference is, that the burn in one started in such a manner that it immediately short-circuited all three phases, while the arc in the other was between only one conductor and ground.

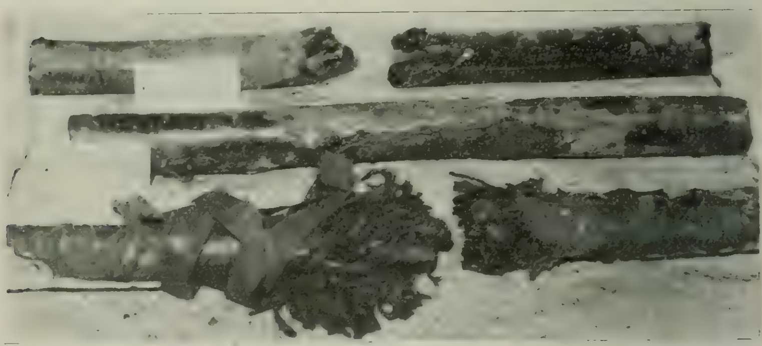

Fig. 9

Two other cables Nos. 141 and 155 broke down under test, made a few hours after the trouble, and line No. 163 had a small hole in the lead which was not discovered until the tunnel was pumped out. Another view of the pieces of burned cable from this burn-out are shown in Fig. 9.

It was not intended at the time that cables were installed to put them in service in the condition shown by Fig. 8, but owing to the

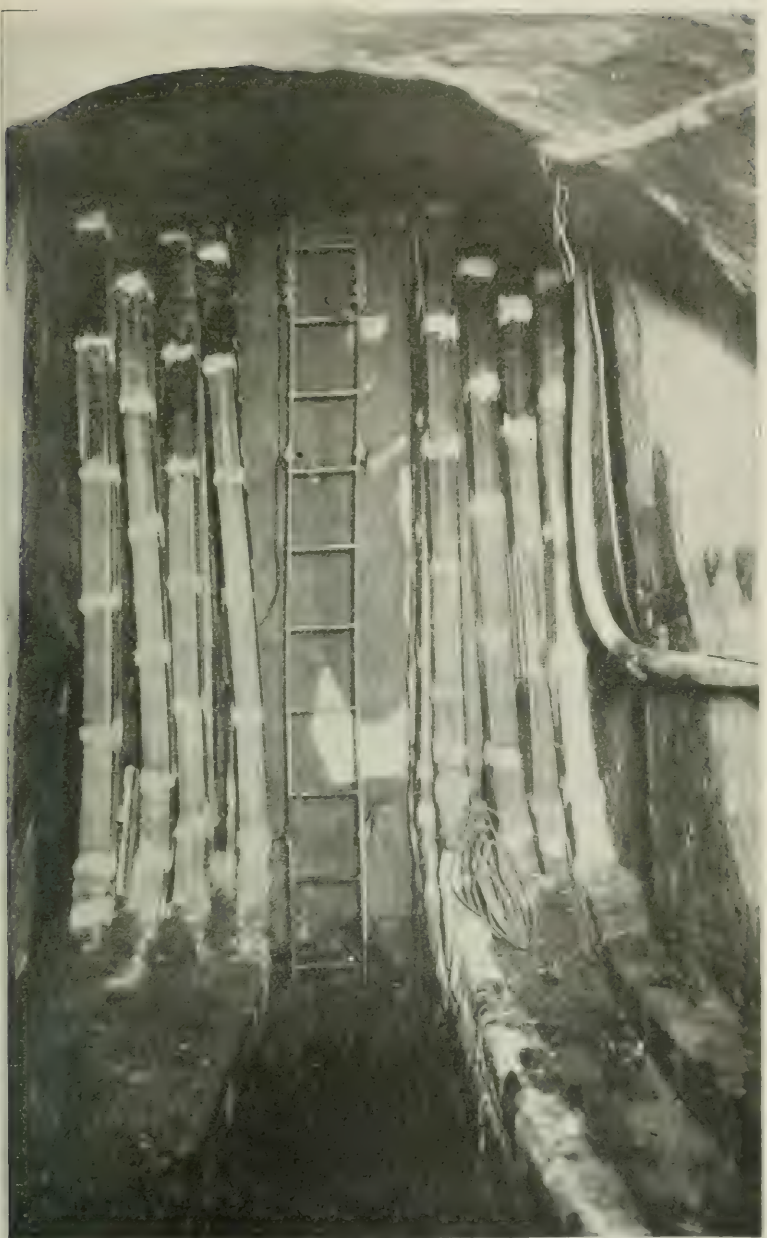

Fig. 10

This experience would indicate that water is of no particular value in protecting cables from each other, and that cables installed under

breaking of a City water main in the vicinity, together with the failure of the pump used in removing the water from the tunnel about the same time, the cables were placed in service so as not to interfere with other work in the vicinity.

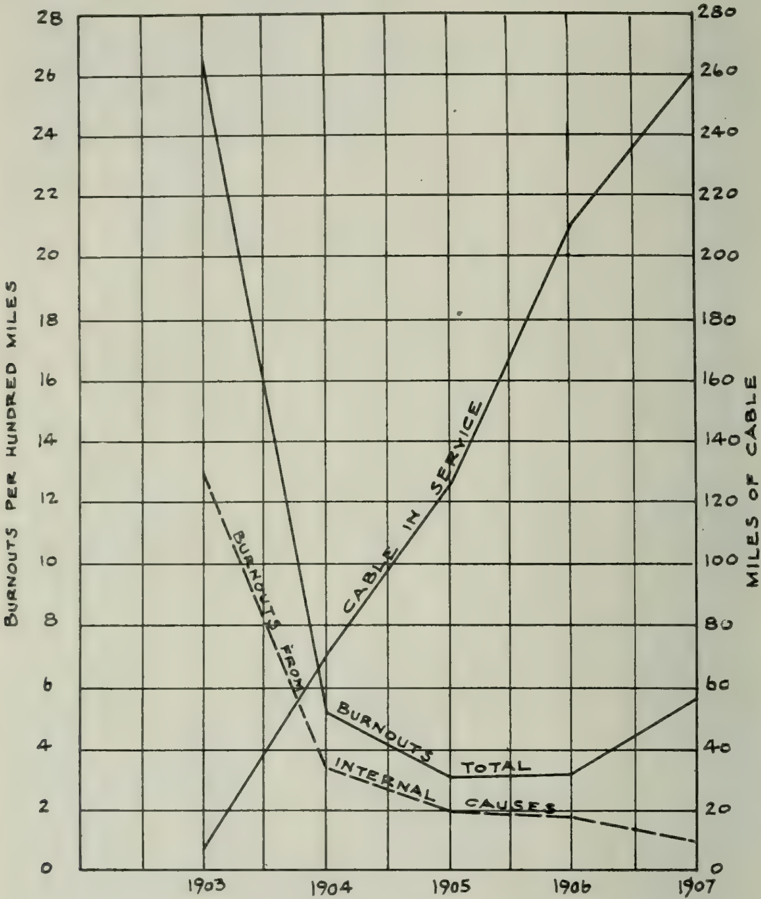

FIG. 11

DIAGRAM SHOWING RECORD OF BURNOUTS OF 9000 VOLT - 3 CONDUCTOR CABLE

The cause of the original burn-out on line No. 128 cannot be definitely determined. It may have been due to some fault in the insulation, or some fine crack or hole in the lead sheath allowing the water to slowly penetrate the paper insulation, or to injury to the lead sheath during installation. The cable had been in service about ten days when it broke down, during which time it had been under water for two days.

water should have the same protection as if the water was not present.

In Fig. 10 is shown the same cables covered with split tile, after the repairs were completed.

After this long description of burn-outs on cables, most of which have been 9000 volt—3-phase transmission lines, it might appear that the distribution of electrical energy in this manner is unsafe, dangerous and unreliable.

But Fig. 11, showing the experience of the Commonwealth Edison Comapny over a period of five years, demonstrates however, that this is not the case. It will be noticed that the number of burn-outs per 100 miles of cable has decreased continuously year by year with the exception of the present year, and that if the burn-outs which have been caused by external injury of the lead sheath be eliminated, the condition has been constantly improving. It is believed that these records will compare favorably with the records of any other Company on similar cables and under similar conditions. With the added information regarding the causes of burn-outs we are confident that we can adopt such measures as will largely reduce the troubles from similar external causes in the future, and thus to be able to again turn the curve of total burn-outs in a downward direction.

It is particularly gratifying to me, to be able to state in this connection that during the period of about five years that this Company has been transmitting energy through underground cables by means of 9000 volt, 3-phase currents, there has been but one failure of a high tension cable joint while in service; and this joint was installed in a manhole in a railroad subway, so that the joint was continuously under water. It is believed that this record in high tension cable splicing is not equalled, nor even approached, by that of any other Company installing high tension underground cables.

DISCUSSION.

Mr. K. B. Miller, M.W.S.E. Underground cables, whether for telephone, telegraph, electric light, or whatever purpose, are all in some measure subject to the hazard of burn-outs. It is true that the signal cables do not carry sufficient current to make them a source of danger in themselves, but unfortunately sometimes those cables get mixed up with others, and may be called upon it such instances to carry very high current, and thus be subjected to the same dangers as the other cables.

President Abbott: The work described by Mr. Roper is one which has attracted a great deal of interest among the engineers of the Commonwealth Edison Co. A few years ago it was considered good engineering to build a conduit line containing as many as 24 ducts in one structure. We occasionally worked with the telephone company in constructing conduit lines, and they also considered it good

engineering to have their conduits laid adjoining ours. After a time their engineers objected to that sort of joint construction and insisted upon a wall of concrete between their ducts and ours. There was considerable discussion among ourselves on the necessity of such dividing walls and on the necessity of installing conduit in several parallel streets so as to reduce the percentage of total cable in any one conduit line. But the first two burn-outs which Mr. Roper has described, occurring in short succession, emphasized the fact that a conduit line containing any number of 9000 volt cables was liable to be totally destroyed and every cable and duct put out of service by the failure of a single one. Profiting by this we have naturally changed our plan of constructing large conduit lines, and now we are cutting them up into smaller sections, putting some of the lines on one side of the street and some on the other, and where that is not possible, separating them with a wall.

The vaporization of tile was also a matter of great surprise to us. These tile, as you know, are made of fire clay and are supposed to be about as fire resisting as any commercial article. After these failures of the conduit lines, I referred the matter to a geologist and asked him if the clay was of poor quality and he replied, (as we might have expected), that no clay would withstand temperature such as this was subjected to—possibly above 5000 deg. F., most fire clay melting down at a temperature of 3000 or perhaps 3500 deg. F.

Another lesson which might be drawn from these failures is that the joints between the tile should be so broken and so made that there would be less possibility of the gases from one duct escaping into an adjoining duct, and even when they are so made an arc on a line in one duct may break through to another duct by melting the intervening walls. Furthermore, the greatest danger in such a conduit line does not necessarily exist in high tension lines, but possibly in a line of much lower voltage but of high current, such as the railway cable, which was the cause of one of the failures mentioned.

With all of our troubles, I think we have reason to congratulate ourselves upon the remarkable freedom which we have had from failures of the joints in our 9000 volt lines. There are about 260 miles of 9000 volt lines, averaging a joint every 400 feet. These joints are made up by men on the street where it is impossible to exercise close supervision; they are often made in a hurry, sometimes in stormy weather, and sometimes in crowded streets, where careful work is difficult to secure, yet so careful and conscientious have these jointers been in their work that our freedom from breakdowns in the joints has been as great, I might say, as though the work has been done in a laboratory.

Mr. P. Junkersfeld, M.W.S.E. This paper is of particular interest, and some of the features have already been thoroughly emphasized in discussion.

There are, however, three points that can possibly stand a little further elaboration. One is the great importance, in these large systems, of getting several different routes for cables. Here in Chicago we have been fortunate in working under conditions where it was usually possible to get conduit routes over different streets or, in the worst event, two or more routes in one street, but in some of the other large cities this has been impossible. Multiplicity of conduit or subways always brings up a commercial consideration, but when we analyze the paper we find that, after all, the total number of burn-outs is very few indeed. As was shown in the last chart, the number has decreased at a rapid rate, so that it is not as large a matter as one might think, when one considers that this system has something like 270 miles of cable in service.

The second point is the very unusual record which has been obtained in the success with joints, is due, first, to proper methods; second, to suitable insulating materials, and third, to careful workmanship.

The third point is the isolation of cables in manholes. Two of the three serious cases mentioned in the paper occurred in the conduit itself. The third case occurred during the construction period and before it was possible to isolate the cable. Isolation is carried out through the entire length of the cable, beginning at the generating station, in every manhole, and ending with the terminal bell in the sub-station. Experience has demonstrated that this is particularly important and should be done promptly and effectively.

In this connection we have with us this evening a man who was associated with me some six years ago, and who was one of the earliest advocates of what we then called isolation of cables. He at that time devised a form of split tile for this purpose. We would like to hear his views on the subject. I refer to Mr. E. N. Lake.

Mr. E. N. Lake, M.W.S.E. I do not believe I can add anything to this discussion that will be nearly as interesting as what we have already heard.

One point in connection with the chart shown on the screen which impressed me was the extraordinary record. I believe the length of the cable system is about 260 miles, and that the joints occur about every 400 feet, and if, out of that number of joints, there have been only four or five burn-outs per year, it indicates three very important facts in connection with the construction,—first, good material in the insulation of the cables; second, very careful installation of the cables; third, very careful work in connection with the jointing.

I think that the company, which the speaker of the evening represents, deserves a great deal of credit for its high class construction, and for the record it has shown.

Mr. R. F. Schuchardt, M.W.S.E. This paper which Mr. Roper has given us is certainly interesting. It is especially interesting to engineers connected with central stations in large cities. The results of such studies determine largely the engineering policy of the com-

panies and thus mark the steps of progress in the development of central station systems. Some of these steps have already been pointed out in the discussion.

The author has described three cases of trouble and has shown us some of the effects. Another place in which the effect is felt with varying severity is the sub-station to which the cable connects. When a short circuit occurs in a cable and lasts for several seconds it generally means that a good deal of the synchronous apparatus running on the system at that time is disturbed. The natural question arises, "how are the station and sub-station protected against the effects of such troubles?" The first condition necessary is, of course, to disconnect the cable from the system the moment a fault develops—and for this purpose overload relays at the station and reverse current relays at the sub-station are used. At the beginning, the overload relays were of the ordinary plunger type, and their use generally resulted in cutting off half a dozen lines, more or less, every time the system was disturbed. A relay with a fixed time element was tried for a time but did not give the desired results. The type most generally used at present has an inverse time element attachment in the form of a bellows and an intelligent use of this relay will generally prevent the opening of switches other than those of the affected line. Breakdowns happen comparatively seldom so it is necessary to study all cases closely as these are our only opportunities to find out anything about the effectiveness of the protective devices installed.

In the first case the author tells about, we discovered a certain weakness in some of the protective devices we had installed, and we immediately proceeded to correct that weakness. Occasionally, however, there are so many attendant conditions which cannot be clearly defined and which may have had considerable influence in the result that we are in doubt as to what action really took place.

In the last case of trouble, the one in the Quarry Street tunnel, line No. 133 broke down on all three phases, which indicated that the protective device did not open the oil switch very promptly. Generally when the "short" holds on for several seconds, when the protective device does not operate promptly, the breakdown which usually starts between one phase and ground is communicated to the other phases and is then, of course, much more violent. The cause of the tardy action of this relay was found, with the result that all the relays are being improved so as to eliminate the defect.

Thus we see "failures" are means to success, for the failures bring about the results which mark the stepping stones in the progressive development of central station system.

Mr Miller: I would ask Mr. Roper what are the most common causes of external injuries which cause burn-outs in power work?

Mr. Roper: We have had several cases where a pick was driven into our cables. In another case a lead pipe thief cut into a cable with a chisel. Other cases have occurred where the cable was injured by other burn-outs. For instance, take the case at 16th and

Morgan Streets; the current at the time of the breakdown, as mentioned, traveled along the lead sheath and then to ground in adjacent manholes. I think that in the past two years we have had more trouble from that, than from any other single cause, that is, the current in the arc at the time of one burnout flowing along the cable and going to ground at some other point where the cable touches something metallic in the ground. That particular form of burnout has been eliminated in our later work by slipping over the cable joint a piece of fibre conduit or sewer tile.

Another cause of trouble, of which we have had several cases, is electrolysis, and all of the electrolysis we get is not from the return current of street car systems. I do not wish to say there is no electrolysis caused by the street car systems, because that would not be correct, but there are some cases where we are inclined to blame the street car company, and we finally learn they are not at fault. I know of one case in particular of that nature, and there have been several other cases where the cable which was withdrawn from the ducts showed unmistakable signs of electrolysis, but on taking electrical measurements it was found that there were no conditions present any time of the day or night for the week or month following, which would produce electrolysis.

Mr. Geo. H. Lukes, M.W.S.E. From the results of these burn-outs it has been shown, as Mr. Abbott says, that it is advisable to divide up conduit lines, putting them on opposite sides of the street, and possibly to sectionalize the same conduit line by separating the ducts with a wall of concrete. I would ask Mr. Roper what modifications in ordinary conduit practice have been decided upon in this direction? At what capacity does it become desirable to sectionalize, and what is the thickness of the proposed wall?

Mr. Roper: As Mr. Abbott said, after the first two troubles occurred, we considered that matter further and decided that conduits which contain sixteen ducts or more should be divided. Duct lines installed since that time, which contain sixteen, twenty, or more ducts, have had a 3-inch wall of concrete through the center. These duct lines have all, I believe, been made four ducts wide, so that in a twenty duct line we have ten ducts (two ducts in width and five ducts in height) on each side of the central wall of 3-inch concrete.

Mr. Schuchardt referred to the way the relays acted in the case at 40th Ave., which was very easily indeed; more like the case of line No. 164, which touched off so remarkably easy. It was the fact that they did touch off so easily which gave us the first idea that the troubles were external. These cables being in ducts, separated with two thicknesses of clay tile, we knew that the arc from the first one could not have burned through to injure the second cable.

With regard to the matter of jointing; there was a paper read before one of the branches of the American Institute of Electrical Engineers lately, describing the installations by one of the large cable manufacturing companies. It was stated that this manufacturing

company had installed in various cities in the country about the same total amount of high tension cable—6,000 volts up to 10,000 or 15,000 volts working pressure—and the representative of the company referred to, in reading the article, was very enthusiastic over the excellent record made by his company. That company I know, stands very high in its record of cable work. However, it was stated that in the cables described there had occurred nine failures of cable joints in service, where our record is only one.

Mr. Lukes: In reference to this matter of making high tension joints; as I am no longer connected with the Commonwealth Edison Company it is perhaps proper for me to explain that the jointers are mostly men who have learned their trade with the Company and that in my opinion great credit is due to the men who have supervised their education. The engineers and the foreman, and sub-foremen in the Underground Department who by exercising good judgment in the selection of promising men and who by taking infinite pains in training them have secured these results, are the ones to whom a large part of the credit is due.

Prof. Morgan Brooks, M.W.S.E. What would be the relative disadvantage of overhead construction as compared with underground, as to reliability?

Mr. Roper: I think there would be more interruptions on overhead lines on account of lightning and similar causes. Our own experience has been very limited. We have only a single overhead high voltage line at present. I think the overhead construction has been used under conditions of cross-country routes with probably much less trouble. Nearly all trouble on our single high-tension overhead line occurs at the corners and crossings, and at such places, on account of insufficient head room, we were unable to separate the wires sufficiently.

Mr. Lukes: On a system containing, as this does, some 270 miles of lead sheath on high tension cables, the freedom from electrolysis means, evidently, that some particular precautions were taken to protect the lead sheath. I would ask what, in general, were these precautions?

Mr. Roper: The scheme of protection used here in Chicago by the company with which I am connected, is similar to that, I believe, used by other cities and companies. In brief, it consists in trying the lead sheaths of the cable together at points where they separate and travel different routes, and also in tying the lead sheaths of the cable to the negative bus of the railway sub-stations, or to a point on the rails nearest to the station. That is sometimes a difficult thing to do, especially where there are two independent railway systems: as, for instance, an overhead elevated railway system and a surface line. In some cases in this city there are differences of from 20 to 50 volts between the street car rails and an elevated structure immediately overhead.

PROCEEDINGS OF THE SOCIETY.

MINUTES OF THE MEETINGS.

REGULAR MEETING MARCH 4TH, 1908.

A regular meeting of the Society (No. 627) was held Wednesday evening, March 4th, 1908. The meeting was called to order at 8.20 p. m., with President Loweth in the Chair and about 60 members and guests present. The minutes of the meetings of the Society held February 5th and 19th were read and approved.

The Secretary reported from the Board of Direction the election into membership of the following:

	Grade.
Lawrence H. Taylor, Chicago	Associate
Ernest Lunn, Chicago	Active
Winfred G. Armstrong, Chicago	Active
Edward G. Slocumb, Beardstown, Ill., transferred from Junior to	Active
William H. Crumb, Chicago	Active
John C. Blaylock, Chicago	Active
Frederick A. Bergbom, Chicago	Associate
John T. Stewart, Paxton, Ill	Active
P. Albert Poppenhusen, Chicago	Associate
Fred N. Wilson, Chicago	Junior
William T. Main, Chicago	Active
Wilhelm Rieth, Chanute, Kans	Junior
W. S. Marston, S. I., N. Y., transferred from Junior to	Active
Joseph Harrington, Riverside, Ill	Active
S. Morgan Bushnell, Chicago	Active
John A. Garcia, Chicago	Active
Ellis C. Soper, South Pittsburg, Tenn., transferred from Junior to	Active

Also that applications for membership had been received from the following:

Alfred W. Kennedy, Harvey, Ill.
Percy Sawyer, Waukesha, Wis., (transfer).
Charles A. Prout, Wheaton, Ill.
Edwin B. Whitcomb, Neosha, Mo.
Hugh J. Fixmer, Chicago.
Walter T. Ray, Pine Beach, Va.,)transfer).
William Meier, Chicago (transfer).
John J. Harman, Kewanee, Ill.
John H. McElroy, Chicago.

Announcement was made that word had been received of the death of one of our old members, Mr. Z. A. Enos, Springfield, Ill., on December 8th, 1907, and also of the recent death in Florida of our member, Mr. James Dun, of Chicago, February 23rd, 1908. Mr. W. C. Armstrong offered a resolution, which was duly carried, that the Chair appoint Committees to prepare memorials of these active members of the Society for publication in the JOURNAL.

The Secretary stated that a communication had been received—a petition for an amendment to the By-Laws—which had been laid before the Board of Direction, who transmit the same to the Society with a general recommendation that the subject be further considered with the object in view of so changing the By-Laws that absence from meetings, by members of the Board of Direction, can be excused for cause. The Petition is as follows:

To amend the fourth paragraph of Sec. 2 of Art. III of By-Laws to read:

"Any member of the Board of Direction, excepting a Past-President and excepting a Vice-President living more than fifty miles from the headquarters of the Society, who shall absent himself from three consecutive and regularly called meetings of the Board without having previously obtained its consent, shall cease to be a member of the Board, and the Board shall proceed to fill

his place for the unexpired term. Due notice of such action shall be sent to the absent member."

Mr. Abbott offered a motion that the report of the Committee be adopted and Mr. Junkersfeld moved an amendment to the proposed amendment to the By-laws, which is as follows:

"Any member of the Board of Direction, excepting the Past-Presidents and a Vice-President living more than fifty miles from the headquarters of the Society, who shall absent himself from three consecutive regular meetings of the Board, unless excused by he Board, shall cease to be a member thereof, and the Board shall proceed to fill his place for the unexpired term. Due notice of such action shall be sent to the absent member. The Board of Direction, however, may excuse the absence of any of its members from a meeting, upon presentation in writing at that or at the next regular meeting of the Board, of a reasonable excuse for such absence."

This amendment to the original report was adopted, and it was ordered that it be submitted to the Members of the Society for adoption or rejection, by letter ballot.

There being no further business before the Society Mr. George M. Brill, M.S.W.E., was introduced, who presented his paper on "Location, Arrangement and Construction of Manufacturing Plants." This paper had been printed and sent out in advance, so it was read in part only by the author. Lantern slide views were then shown, illustrative of various manufacturing concerns.

Discussion followed from President Loweth and Messrs. W. L. Abbott, C. K. Baldwin, G. W. Williams, D. C. Tanner, P. M. Chamberlain, with a closure by the author.

The meeing adjourned at 10:15 p. m.

Electrical Section, March 11, 1908.

A regular meeting, No. 31 of the Electrical Section (being No. 628 of the Society) was held Wednesday evening, March 11th, 1908. The meeting was called to order at 8:20 p. m. by Mr. D. W. Roper, Chairman, and with nearly 100 members and guests present. The minutes of the meeting held February 14th were read and approved.

There being no further busines to bring before the Section, the Chairman introduced Prof. Morgan Brooks, M.W.S.E., University of Illinois, Urbana, Ill., who addressed the meeting on "The Operation of Alternators in Parallel." The speaker treated of the parallel operation of synchronous machines and the conditions governing their sucessful operation. He also presented a scheme for the self-synchronizing of alternators. Charts, with sliding and rotating pointers were used to illustrate the paper. Through the courtesy of the Commonwealth Edison Company some apparatus was installed to demonstrate the synchronizing of some of the alternators at the plants of that Company.

Discussion followed from Messrs. D. W. Roper, James Lyman, P. Junkersfeld, A. A. Radtke of Armour Institute, W. L. Abbott, E. F. Smith, George H. Lukes, with a closure from Prof. Brooks.

The meeting adjourned at 10:50 p. m.

Extra Meeting, March 25, 1908.

An extra meeting of the Society (No. 629) was held Wednesday evening, March 25th, 1908. The meeting was called to order about 8:15 p. m. with Mr. A. Reichman in the Chair, and about 65 members and guests present.

The Secretary announced that the next meeting of the Society would be held April 1st, when Mr. W. M. Torrance, M.W.S.E., of New York, would present his paper on the reinforced concrete work in connection with the Hudson River tunnels.

There being no other business, Mr. J. N. Darling, M.W.S.E., was introduced who read his paper on "Some Features of Construction of the South Side Elevated Railway." The paper was illustrated by a number of lantern slide views.

Discussion followed from Messrs. W. B. Storey, Jr., J. C. Fruit, W. B. Jackson, A. Reichmann, M. S. Ralls, E. E. R. Tratman, J. G. Spielman and the author—Mr. Darling.

The meeting adjourned about 9:50 p. m.

Regular Meeting, April 1, 1908.

A regular meeting (No. 630) of the Society was held the evening of Wednesday, April 1st. The meeting was called to order at 8:20 p. m., with President Loweth in the Chair and about 75 members and guests present. The minutes of the meetings held March 4th and March 25th were read and approved. The President appointed Messrs. William Artingstall and Ernest McCullough a committee to canvass the letter ballots received, voting on the amendment to Section 2, Article II, of the By-Laws, and to report later the result of the canvass. The President announced, also, the appointment of the following committees: Messrs. Onward Bates, Isham Randolph and W. B. Storey, Jr., to prepare a memorial of our late member, Mr. James Dun; and Messrs. L. P. Morehouse, E. C. Carter, and F. G. Ewald to prepare a memorial of Mr. Z. A. Enos.

The Secretary reported from the Board of Direction that at the regular meeting held March 31st the following persons had been elected members of the Society:

	Grade.
Percy Sawyer, Waukesha, Wis., transferred from Junior to	Active
Charles A. Prout, Wheaton, Ill.	Active
Hugh J. Fixmer, Chicago	Junior
William Meier, New York, transferred from Junior to	Active
John J. Harman, Kewanee, Ill.	Active
Elgie R. Skinner, Chicago, transferred from Junior to	Active
J. W. Woermann, Minooka, Ill.	Active

Also that applications for membership had been received from:

D. E. Willard, Chicago.
A. C. Greaves, Sturgeon Bay, Wis.
Henry H. Decker, Winona, Minn.
Hugo M. Wilke, Chicago. (Transfer.)
Charles M. Naylor, Chicago.
Wm. J. Crumpton, Chicago.

The canvassers of the ballots on the amendment to the By-laws, Section 2, Article III, reported that 217 ballots were received, of which 208 were in the affirmative and 9 in the negative. The President then declared the amendment to be in force.

There being no further business to bring before the Society, the Chairman introduced Mr. W. M. Torrance, M. W. S. E., of New York, who read his paper on "Reinforced Concrete Structures in the Hudson River Tunnel Work." This was illustrated by a large number of lantern slide views, and was full of interest to those present. Some discussion followed from Messrs. J. M. Ewen, M. F. Ewen, W. B. Jackson, T. L. D. Hadwen, E. C. McCullough, C. R. Dart, President Loweth, and the author.

The meeting adjourned at 10:25 p. m.

Electrical Section, April 10, 1908.

A regular meeting (No. 32) of the Electrical Section (No. 631 of the Society) was held Friday evening, April 10th. The meeting was called to order at 8:20 p. m. by Mr. D. W. Roper, Chairman of the Section, and about twenty-five guests and members present. The minutes of the preceding meeting held March 11th, were read and approved.

Mr. J. C. Kelsey, of the Kellogg Switchboard and Supply Co., was then introduced, who read his paper on "The Relation between the Banker and the Engineer." Discussion followed from Messrs. D. W. Roper, A. Bement, W. B. Jackson, E. N. Lake, J. R. Cravath, Ernest Lunn, E. F. Smith and the author.

The meeting adjourned about 9:50 p. m.

EXTRA MEETING, APRIL 15, 1908.

An extra meeting of the Society (No. 632), was held Wednesday evening, April 15th, 1908. The meeting was called to order at 8:15 p. m., with President Loweth in the Chair and about seventy members and guests present. There was no business to bring before the Society, but the President announced the appointment of a committee, of Messrs. W. H. Finley, H. E. Horton, Andrews Allen, C. R. Dart, J. H. Prior, R. Modjeski, and W. C. Armstrong—to collect, collate and edit, for publication in the JOURNAL, reports of tests of compressive members for bridges and other metallic structures.

Profesor A. N. Talbot, M.W.S.E., was then introduced, who presented his paper on "Tests of Cast Iron and Reinforced Concrete Culvert Pipe," which tests had been made at the University of Illinois, Urbana. As this paper had been printed and sent out in advance, it was not read, but the author, with the aid of a number of lantern slide views, explained how the tests had been made and the results obtained. Discussion followed from the President and Messrs. C. H. Cartlidge, R. J. Mershon, A. S. Baldwin, W. E. Wood, E. N. Layfield, T. L. Condron, A. Reichmann, C. W. Baldridge, T. L. D. Hadwen, I. O. Baker, B. J. Ashley, and the author.

The meeting adjourned about 10:15 p. m. J. H. WARDER, *Secretary.*

BOOK REVIEWS

RAILROAD ENGINEERINGS Vol. II., Elements of Railroad Engineering, by William G. Raymond, C. E., LL.D., Professor of Civil Engineering and Dean of the College of Applied Science, The State University of Iowa. 1st Edition, 8vo, 465 pages, 107 figures, 18 plates, cloth. Price, $3.50. John Wiley & Sons, New York. 1908.

The author has divided this work into three parts with an introduction and an appendix. In the introduction he has set down briefly some ideas of railroad political economy. Starting with the apothegm, that in America railroads are built for the single avowed purpose of making money for the projectors, the author takes up the possible motives for the inception of a railroad enterprise and proceed through the various steps of organizing a company, obtaining a franchise, the issue of stocks and bonds, construction and organizing for operation. Cause of railroad failure, over capitalization, stock watering, etc., are then reviewed. The introduction closes with a discussion of railroad valuation, the relation of the railroad to the public and the duty of the engineer in locating and building a line with reference to expected traffic.

Part I. Permanent Way: Covers in 10 chapters the physical necessities of a railroad, taking up in some detail the alignment, horizontal and vertical; the rail, its metallurgy, form and manufacture; joints and rail fastenings; ties, durability of various woods and preservative processes; ballast and roadbed standards; openings and minor structures; turnouts, yards and side tracks; rail elevation on curves and signaling. In these 110 pages the author has covered a large subject in a very concise and instructive manner. The illustrations are taken from standards and existing layouts of our best railroads.

Part II. The Locomotive and Its Work: The general scope of the seven chapters given to this subject is to determine the underlying principles for the design of grade line and alignment. Types of locomotives are illustrated, their hauling capacity, resistance to be overcome under various alignments and grades; cost of operation and variation in cost due to rise and fall, distance and curvature, are discussed theoretically and practically. This part is in fact a short treatise of 112 pages on the economics of railroad location.

Part III. Railroad Location, Construction and Betterment Surveys. Five chapters are here devoted to the methods used in applying the principles derived in part II to the location and construction of the line. The three surveys, reconnoissance, preliminary survey and location survey, are described in some detail in three chapters, followed by a chapter on construction and one on betterment surveys. The entire subject is covered in 86 pages and is treated in a very brief way, giving the student but a tast of this great field.

The appendix consists of a paper by W. D. Taylor, M.W.S.E., and Mem. Am. Soc. C. E., on the location of the Knoxville, La Folette and Jellico Railroad, of the Louisville & Nashville system, taken from the Trans. Am. Soc. of Civil Engineers, Vol. LII., together with parts of the discussion. This paper is too well known to call for remarks here. The author's idea of crystalizing the principles of location in the minds of his students by a concrete example is to be commended.

Like all other works attempting to cover a large subject in a broad but condensed way, this work might be criticised in many details, but as a general text book it is a valuable addition to the literature on this subject. The name of the publishers is a sufficient guarantee as to type, paper and binding.

G. H. H.

PRACTICAL PHYSICS: A Laboratory Manual for Colleges and Technical Schools, by W. S. Franklin, C. M. Crawford and Barry Macnutt (Lehigh University). The Macmillan Company, New York. Three volumes, cloth; pp. 173, 160 and 80; many cuts. Price, \$1.25, \$1.25 and 0.90, respectively.

What with the demands of the practical man on the one hand, and those of the precision man on the other, the ordinary student of the present day, be he technical student or not, may well be puzzled. It would seem that a path lying fairly between these extremes might be easy to define and easy to follow. To obtain results as close as conditions warrant, to work with expedition and accuracy, to lay plans, to execute, to interpret and report, are requirments in all fields of activity. Any arrangement of work for students which can be fairly said to embody the items of the preceeding sentence is deserving of serious attention in this day of education at high pressure. This set of books, entitled "Practical Physics," follows this middle path admirably.

The matter of these three small volumes may be summarized as follows: Volume I has 61 experiments upon measures of length, angle, mass, time; mechanics and heat. Volume II with 47 experiments is devoted entirely to simple work in electricity and magnetism and to advanced electrical measurements. Volume III with only 24 experiments treats the subjects of light and sound. An all too short introduction of some twenty pages touches upon the following important matters more or less adeqnately,—the object of a physical laboratory course, prepartion before beginning the test, acquaintance with the apparatus, form and matter of reports, recording of observations, errors of obsevations, treatment of data, plotting of curves.

The spirit of the books is good. Although a few crude experiments are included, the majority "are susceptible of a high degree of accuracy, and the student should throughout his course undertake to attain the highest accuracy possible with the material in hand." The student is expected to originate and lay out his own tabular forms for each exercise, before entering the laboratory. The arrangement of experiments in each group shows evidence of attention to proper sequence, and the matter under each experiment seems adequate and yet not too full. A few physical tables are given. These are placed in the body of the text. Each volume contains a short but fairly complete index. The cuts are clear and carefully drawn. There are nearly 200 in all, and the greater number of them are diagramatic. With such figures before him, the student using these volumes may be expected to illuminate his reports with neat and accurate sketches. The typography is well up to the high standard of the publishers.

These volumes form a valuable addition to the already large number of carefully prepared American college texts books. A. W. M.

STEEL WORKS ANALYSIS: By John Oliver Arnold and F. Ibbotson, respectively Professor and Lecturer in Metallury at the University of Sheffield. The Macmillan Company, New York. Cloth; 7½ by 5 ins.; pp. 468; illustrated. Third edition; 1907. Price \$3.50 net.

This work, as indicated in the preface to the first edition, was written specially for the use of assistants in steel works laboratories. Accordingly we find that it treats of approved methods of analysis of all materials used in the iron

and steel industry. The authors do not confine themselves to the examination of iron ore, and iron and steel, but include also fuels, refractory material, water and white metals. They dwell at length on the determinations of such constituents as arsenic, chromium, molybdenum, vanadium, titanium, and tantalum, in order to meet the growing tendency in modern steel-making of introducing small quantities of rare metals. The methods selected are the most modern and approved. The manner in which they are presented is very good, fairly concise and accurate. The principles involved in the different methods are briefly pointed out, and the various steps in the analysis are properly separated, and each put under an appropriate heading.

On the whole, the book makes a good impression and should prove a welcome addition to the working library of every metallurgical chemist.

L. T.

CONCRETE CONSTRUCTION: METHODS AND COST. By Halbert P. Gillette and Chas. S. Hill. 690 pp., 306 illustrations, many tables, etc. 6 by 9 ins, cloth. Price, $5.00. Myron C. Clark Pub. Co., Chicago and New York.

Mr. Gillette is Managing Editor of *Engineering-Contracting*, formerly Associate Editor of *Engineering News*, and is a practical construction engineer of many years experience. He is the author of Earth Excavation, Rock Excavation, Economics of Road Construction, Hand Book of Cost Data, etc. Mr. Hill is an Associate Editor of *Engineering-Contracting* and formerly held the same position on *Engineering News*. He was the author of the best description of the Chicago Drainage Canal that appeared and was the joint editor with Mr. Buel of the first satisfactory American book on reinforced concrete. As an editor who dealt with the practical side of engineering work, he has been well and favorably known for years. So much for the authors.

A frequent complaint about the new building material, reinforced concrete, is that nearly every man who knows anything has written books on design, and that a great many men who appear to know little have written articles on how to carry on a piece of work. Yet to date, the men who know what such work costs have kept quiet. We have all been collecting fragmentary literature on the subject and the stuff is piling up in cellars, garrets, closets, and spare rooms, much to the disgust of our wives, until we feel like going through it to index and file the valuable material and sell the rest. The chances have been good that in the case of most of us the paper will be burnt as incense to our memory by the executors who come to hunt for our estate after our demise. Our wives and long suffering families will be glad to learn of this new book, for now they can burn or sell the scrap paper.

The authors have given us twenty-five chapters on reinforced concrete (and plain concrete also), beginning with methods and cost of selecting and preparing materials for concrete, and ending with a chapter on the live subject of waterproofing. They have collected in the nearly seven hundred, six by nine inch pages, practically everything of real value that has appeared in print in technical periodicals within the past few years. In addition they have inserted matter that would never have been printed if they had not gone out after it. They have also commented on features that struck them as worthy of comment in the works under review. The result is a book on the economics of concrete construction that should have an immense sale. Every engineer today has more or less concrete work to do, some in the design and more in the construction. Therefore, every engineer will find it to his advantage to possess a copy of this book, for it does not take the place of any book thus far published. It supplements all, for there is not one word on design, and the descriptive part is such as one would expect from a man who was itching to boss the job while he looked on and was not preparing a newspaper description. It is this practical treatment on every page that appeals to the reviewer and should appeal to every man who handles concrete.

The book is not perfect. No book is. For a first book on a particular phase of a subject, it is remarkably complete and so deserving of recommendation that we can well skip criticism. In the opinion of the reviewer it is worth

several times the price even to an old experienced concrete man, and such the reviewer considers himself.

The paper, illustrations and tpography leave nothing to be desired and the book is substantially bound, as is to be expected of works from the house issuing it.

E. McC.

FIELD SYSTEM. By Frank B. Gilbreth, General Contractor, New York. 4½ by 6½ ins., 194 pp. including index, with illustrations and many tables. The Myron C. Clark Publishing Co., New York and Chicago. Flexible leather. Price $3.00.

This is an interesting book, although a clever and efficient advertising scheme for the author, who is a successful contractor in building construction. Mr. Gilbreth is widely known by the form of the contracts he handles, which are based on the "cost plus a fixed sum." The "fixed sum," which is the contractor's profit for his time, etc., is presumably agreed upon with the "owner" before the work begins. The owner pays the actual cost of construction for labor and material, besides the fixed sum to the contractor. The advantage of this method is obvious; any changes in plans, materials, etc., can be made without the owner being subjected to fictitious changes under the name of *extras*; all bills and labor and material are subject to the scrutiny of the owner, and the contractor receives a fixed sum to pay him for his skill, good management, and use of his plant, and takes a minimum of risks. This "field system" is a very clever and well devised arrangement of forms and accounts kept on each job, showing day by day the material ordered and received, the men employed, the progress of work, etc., etc., wherever the work may be. These forms and reports are made out, and copies go to the New York office of the contractor, and also to the owner, and each knows the progress of the work and how much is yet to be done.

The book now presents, in a very convenient form, to those in charge of the work, the many rules (there are 573 of these) and instructions governing the operation of the several classes of workmen, and their superintendents,—what had previously been given out in more cumbersome blue prints and typewritten matter.

At first glance it would seem that there was a multiplicity of forms, and that there would be a great deal of clerical work to be done, but further study indicates that these have been evolved from practice and experience, and that all these forms have an object,—namely, to keep a full, detailed statement of the progress of the work, including the cost of material and labor (under separate headings), and which can be compared by the owner or contractor, with the original estimate of the cost of the work, and to know whether the total cost, on completion, is within the original estimate, and if not, why not.

The rules printed in the book cover a wide range of subjects, and are open to the criticism that some seem unnecesssary, and some appear to duplicate other rules, and that they might be rearranged in a more logical order and sequence; but this is a minor point. The proper and judicious creation and observance of such rules should tend toward greater harmony, unity, and effectiveness in the working force, resulting in better and more economical construction. This, again, is to the advantage of the owner, who, paying for the actual cost of construction, has the benefit of such reductions.

As has been previously remarked, the book is interesting, and would give to engineers many hints and suggestions, which could be used by them in their own work to great advantage,—namely, the introduction of a *system* into the execution of their work, to the advantage of all concerned.

TRADE PUBLICATIONS.

STEEL SHEETING. George W. Jackson, Inc., 169 W. Jackson Blvd., Chicago. Catalogue; paper; 7 by 10 inches; pp. 69.

This pamphlet presents many illustrations of construction work where this system of interlocking steel sheeting is being used, which is recommended for

the construction of deep foundations, building of sewers, laying of water pipes, or anything requiring excavation to extreme depths.

Throughout the catalogue are scattered, also, a number of fac-simile letters from users of this sheeting.

PIPE FLANGES. American Spiral Pipe Works, Box 485, Chicago. Catalogue; stiff paper cover; 8 by 10 inches; pp. 94; illustrated.

Forged and rolled steel pipe flanges are shown, as well as corrugated copper and annealed steel gaskets, wrought iron and spiral riveted pipe, etc. There is a wide range of use for this excellent line of pipe and fittings, in both steam and hydraulic engineering.

SPRINGS FOR RAILWAY AND ELECTRIC TRAFFIC SERVICE. Standard Steel Works, Philadelphia, Pa. Catalogue; paper; 6 by 9 inches; pp. 36; illustrated.

This catalogue presents a few of the more important types of springs now in use on steam and electric roads, and illustrates the conditions under which the springs are manufactured.

EXPANDED STEEL SYSTEM, REINFORCED CONCRETE. Northwestern Expanded Metal Co., Old Colony Bldg., Chicago. Catalogue; paper; 6 by 9 inches.

This pamphlet relates to "theory and tests of reinforced concrete beams," and contains much of interest to those engaged in the planning and construction of work in reinforced concrete.

STEAM SHOVELS. Atlantic Equipment Co., Railway Exchange, Chicago. Catalogue; stiff paper cover; 6 by 9 inches; pp. 42; fully illustrated.

The claim made for the Atlantic Steam Shovel is its simplicity in design, highest possible speed, minimum of wear, moderate weight, highest quality of materials and workmanship.

Pamphlet No. 10014, accompanying the above catalogue, presents reports from users of the steam shovels.

LIFTING MAGNETS. Cutler-Hammer Clutch Co., Milwaukee, Wis. Booklet; paper; 5 by 3½ inches; pp. 30; illustrated.

The subject matter of this booklet originally appeared in Cassier's Magazine, October, 1907, and the booklet is printed in the form of a miniature copy of that magazine. It traces briefly the development of the lifting magnet, and illustrates the different kinds of magnets used for handling pig iron, metal plates and other classes of material. Copies may be had free by addressing the Cutler-Hammer Co.

STEAM TURBINE MACHINERY. De Laval Steam Turbine Co., Trenton, N. J. Bulletin 501; paper; 4½ by 7 inches; pp. 28; illustrated.

This little bulletin illustrates and describes Turbine Engines—separate or driving Dynamos or Blowers; Centrifugal Pumps—turbine or motor driven, etc. The illustrations are fine examples of the engraver's art and the text is very readable.

EXPANSION BOLT AND SHIELD. Diamond Expansion Bolt Co., New York. Catalogue 44-E; paper; 9 by 6 inches; pp. 19; illustrated.

This catalogue illustrates and describes the many uses of the expansion bolt and shield and presents its advantages for anchoring machinery, etc., to brick or masonry structures or foundations.

INDUSTRIAL AND MINE CARS. Kilgore-Peteler Co., Minneapolis, Minn. Catalogue; paper; 9¼ by 6¼ inches; pp. 56; illustrated.

Many different kinds of cars are shown in this catalogue for handling every class of material, on narrow gauge railways, for mines, shops, saw mills, power plants, plantations, docks, warehouses, quarries, etc.

LIBRARY NOTES.

The Library Committee wishes to express thanks for donations to the library. Back numbers of periodicals are desirable for exchange and in completing valuable volumes for our files.

Since the issue of the JOURNAL for February, 1908, we have the pleasure to report the following additions to the library and gifts from donors named:

MISCELLANEOUS GIFTS.

Scientific Publishing Co., Manchester, England.
"Stationary Steam Engines," by William H. Fowler. Cloth.
"Electrical Engineers' Pocket Book, 1908," by William H. Fowler. Leather

John Wiley & Sons, New York.
"The Elements of Railroad Engineering," by W. G. Raymond, 1908. Cloth.
"Methods for Earthwork Computations," by C. W. Crockett, 1908.

Myron C. Clark Publishing Co., Chicago.
"Concrete Construction—Methods and Cost," by H. P. Gillette and C. S. Hill. 1908. Cloth.
"Field System," by Frank B. Gilbreth. 1908. Morocco.

Reginald Peldham Bolton, New York, "Elevator Service," by R. P. Bolton. 1908. Cloth.

American Iron & Steel Association, James M. Swank, Gen'l Mgr., "Directory of Iron and Steel Association of the United States, 1904." Cloth.

Illinois Board of Charities, Springfield, Ill. Quarterly Bulletin, October, 1907. Pamphlet.

Water Board of Lawrence, Mass. Report for 1906. Pamphlet.

Brookline, Mass., Water Dept. Report, 1907-8. Pamphlet.

State Board of Health, New Jersey, 31st annual report. 1907. Cloth.

New York State Engineer & Sureyor, Albany.
Annual Report for 1906. Cloth.
Supplement to Annual Report for 1906. Cloth.

EXCHANGES.

Lewis Institute, Chicago, Director's Report for 1907. Pamphlet.

Institution of Civil Engineers, London, Minutes of Proceedings, 1906-7, Part 4, Vol. CLXX. Paper.

National Association of Cotton Manufacturers, Boston. Transactions for 1907. Bds.

American Society of Mechanical Engineers, New York. Year Book for 1908. Cloth.

Engineers' Club of Central Pennsylvania, Directory of Club for 1908. Morocco.

Smithsonian Institution, U. S. National Museum, Washington, D. C. "Report on the Progress and Condition of the U. S. National Museum, 1907." Cloth.

Junior Institution of Engineers, London, Journal and Record of Transactions, 1906-7. Cloth.

American Gas Institute, New York, Proceedings, Western Gas Association for 1906. Cloth.

Association of Railway Superintendents of Bridges and Buildings, Proceedings for 1907. Pamphlet.

Canadian Society of Civil Engineers, Montreal, Transactions, Jan.-June, 1907. Vol. 21, Part 1. Pamphlet.

American Society of Civil Engineers, New York, Constitution and List of Members, 1908. Cloth.

Institution of Electrical Engineers, London, Proceedings, Nov.-Dec., 1907. Part 187. Paper.

Railway Signal Association, Bethlehem, Pa. Proceedings for 1905-6. Two pamphlets.

Brooklyn Engineers' Club, Brooklyn, N. Y. Proceedings, Constitution, List of Members, etc., 1907. Paper.

American Institute of Architects, Washington, D. C. Proceedings for 1907. Paper.

Roadmasters and Maintenance of Ways Association. Proceedings, 25th Annual Convention, 1907. Pamphlet.

Indiana Engineering Society, Indianapolis, Ind. Proceedings for 1906-1907. Two pamphlets.

American Society of Heating and Ventilating Engineers, New York, Transactions for 1906. Vol. 12. Cloth.

Association of Water Engineers, London. Transactions. Vol. XII, 1907. Cloth.

University of Illinois, Urbana. Bul. No. 18. The Strength of Chain Links. By Goodenough and Moore. Sept., 1907.

GOVERNMENT PUBLICATIONS.

U. S. Geological Survey, Dept. of Interior.
  - Bul. 331—Portland Cement Mortars and their Constituent Materials. 1908. Pamphlet.
  - Bul. 332—Report of the United States Fuel-Testing Plant at St. Louis, Jan. 1906 to June 1907. Pamphlet.

U. S. Dept. of Agriculture, Forest Service. Pamphlets.
  - Circular 141—Wood Paving in the United States. C. L. Hill.
  - Circular 142—Tests of Vehicle and Implement Woods.
  - Circular 144—The Relation of the Southern Appalachian Mountains to the Development of Water Power. Pam.
  - Circular 145—Forest Planting on the Northern Prairies.
  - Circular 143—The Relation of the Southern Appalachian Mountains to Inland Water Navigation.

U. S. Department of Commerce and Labor. Report of Superintendent of Coast and Geodetic Survey, 1907. Cloth.

U. S. Department of Commerce and Labor. Bureau of the Census, Mortality Statistics for 1906. Cloth.

Interstate Commerce Commission.
  - 21st Annual Report of the Interstate Commerce Commission, 1907.
  - 19th Annual Report of Statistics of Railways in the United States, 1906. Cloth.

U. S. War Department, Chief of Engineers. Report of Examination of Ohio River, Jan. 10, 1908. Pam.

MEMBERSHIP.

Additions to Membership:	*Grade*
John J. Harman, Kewanee, Ill.	Active
William Meier, New York, N. Y., transfer from Junior to	Active
Charles A. Prout, Wheaton, Ill.	Active
Percy Sawyer, Waukesha, Wis., transfer from Junior to	Active
Elgie R. Skinner, Chicago, transfer from Junior to	Active
J. W. Woermann, Chicago	Active

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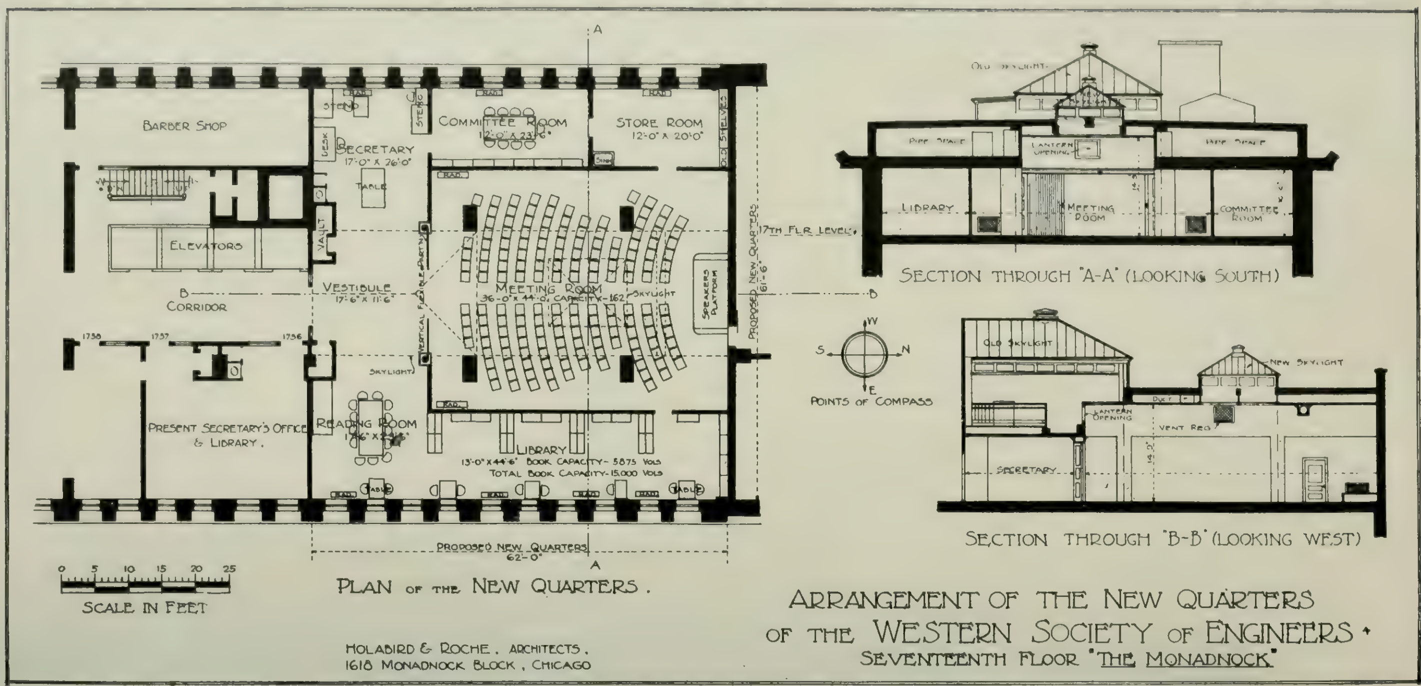

THE NEW QUARTERS FOR THE WESTERN SOCIETY OF ENGINEERS.

(See page 451.)

Journal of the
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THE WROUGHT COMPRESSIVE MEMBER FOR BRIDGE TRUSSES

By H. E. Horton, M.W.S.E.

Read October 2, 1907.

It is subtle and illusive and may side step.

It is composite, and not homogeneous.

No law written of proper relation and proportion of constituent parts.

Cannot deform without shear. Accept and fully provide for it, that is, the shear.

Applied science useful. Be sure you have the right basis in making application.

Successful practice the only sure instructor.

Mathematical investigation only safe when justified by practice.

Sound judgment and clear perception necessary to recognize proportion and relation.

The engineering profession has the ability to understand relations and proportion.

With understanding of relation and proportions, wrought compressive members may be so designed and built of any size with all the certainty of satisfactory result, as of any physical thing designed and built by man.

A leading engineering journal of international reputation in a recent issue has made the broad statement that failures in wrought metal frame structures have all developed from buckling of the compression members, proving the general rule, by noting only one exception where tension members had failed and that due to deterioration by rust. As this was a review of a large number of cases, it is surely evidence that research as to the compression member is not only desirable but necessary. We also have at this time in the col-

umns of the technical press, by correspondence, evidence of a renaissance in the mathematical investigation of compression members and nothing as to the proportion of the elements from which a compressive member is built up.

The design and proportion of compressive members for an open frame structure, like a bridge span, is one of compromise and concession. If the conditions demand only the ability to support weight like an individual column supporting a girder, with uniform distribution of load over the entire area of the column, it is well established that a section of uniform thickness of material in a triangle, in a circle or a square figure, are the most efficient; provided that we can produce by process of manufacture such a figure of homogenous material. However, it is idle to speculate on the efficiency of any exact form of column when the conditions demand that the compressive member must be built up of sections or segments, in practice generally riveted together.

Further the difficulties of making panel connections in truss work are such as to suggest the compressive members, open on one or more sides. This open or lattice member is always made with a material loss of efficiency as to the total weight of material in the member. A typical case will represent a direct loss of full 30% when two channels or similar sections are used, laced on two sides and will generally reach 100% when four angles or similar sections are used, laced on four sides; illustrating the good engineering maxim, that you cannot "eat your cake and keep it."

We cannot economically connect to an enclosed triangular or circular section; in fact the cost of such connections to either of these figures will generally represent more cost than the percentage lost, as indicated above, in developing the open figure.

The enclosed box section presents greater possibilities of connection and lacks but a trifle in efficiency as compared with the triangle, which is greatest, and circle next; these differences can readily be ignored. It may, and probably will develop that such box figures, in the evolution of design, will find its place when maximum sections are required.

Flanged plates with riveted connections were used 30 years ago to form triangular sections. More recent years we have seen circular columns built up of longitudinal sections generally with projecting flanges through which the rivet connections were made. This section was popular and in very extensive use for many years. Box sections have been in use through all periods and with favorable conditions are at the present day.

We have little experimental and definite knowledge of the action of steel in built up compression members. Specimen tests have been carried out on solids and small pipes through many years. Our experience shows full sized members, tested to destruction, fail at less than the computed strength. It is a case of the strength of the composite member being determined by the weakest elementary unit and the further fact of want of cohesion of the parts.

It is quite usual practice in building a structure of any considerable importance to have tests to destruction of tension members, while with the compression members tests are only made on samples to be certain as to the character of the material used. An individual tension member, maximum eye bar, will scarcely cost $200, while we see in practice compression members of size to require a testing machine of 15,000 tons capacity and one such column would cost $10,000. It is scarcely to be hoped that comprehensive tests of such sizes will be undertaken.

It is in fragments only that we have knowledge of such tests as have been made. It seems reasonable to hope that the records of tests of steel that have been made in compression, both in individual pieces and combined members, might be gathered together, edited and published.

Our understanding is that steel of the character used in construction of a composite column or in rolled sections of 100 "radii" yields by bending at somewhere from 30,000 to 35,000 lbs. per sq. in.; that the elastic limit and ultimate strength are essentially the same, that is, the column yields and fails at once under the same load and at the same time.

Our experience and tests as to the reliability and strength of full sized members has been limited generally to pieces not over 30 ft. long and 25 sq. in. of section. In fact our knowledge of the action of such members in the testing machine is very slight, but our knowledge from practice shows rectangular compression members very reliable when designed to standard specifications and sizes within our usual experience in all the well known forms. That we have scarcely more than practice to direct us, is to be regretted.

Length, divided by least Radius of Gyration, (expressed herein as "Radii") is accepted by engineers as an indication of unit value in a compressive member, the application being made by formulas with somewhat varying constants. The least "radii" in all cases showing the largest compressive unit value for material, and here the fact is apparent that the thinner the material the larger the radius. To illustrate:

Member	Section Sq. in.	Radius of Gyration	8 ft. 4 in. equal to	100 "Radii" equal to
4 in. Solid Round	12.5	1	100 Radii	8 ft. 4 in. long
8 in. Pipe, ½ in. thick	12.5	2.5	40 Radii	20.66 ft. long
16 in. Pipe, ¼ in. thick	12.5	5.5	18 Radii	45.8 ft. long
32 in. Pipe, ⅛ in. thick	12.5	11.3	8.8 Radii	94.1 ft. long
64 in. Pipe, 1/16 in. thick	12.5	24.0	4.1 Radii	200 ft. long

These illustrations clearly indicate the necessity for a definite and clear limitation or thickness of material forming a composite column. We recognize the fact that a 4 in. solid round 8 ft. 4 in. long, 100 "radii," is safe to carry 11,000 lbs. per sq. in.; that an 8 in. pipe ½ in. thick at 40 "radii" is safe to carry 16,000 lbs. per sq. in. In the circular form we can readily believe that a 16 in. pipe ¼ in. thick, at 18 "radii" will also safely carry 16,000 lbs. per sq.

in. But a pipe 32 in. in diameter ⅛ in. thick, 8.8 "radii" will also carry a goodly load per sq. in., but I doubt if anyone would expect to load it to 16,000 lbs. per sq. in. A 64 in. pipe 1-16 in. thick 4.1 "radii" we have reason to believe will collapse and fail at less than the load per sq. in. that the 4 in. solid round at 100 "radii" will sustain.

Let me cite the following as an illustration of the necessity of

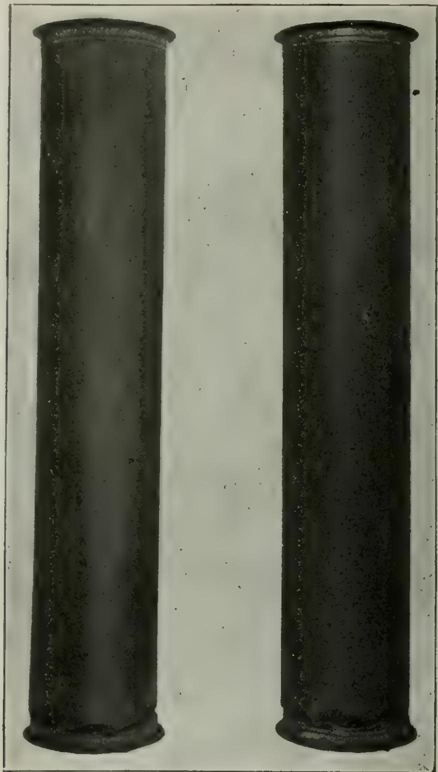


FIG. 1. Two views, at right angles to each other, of the Test Cylinder after failure.

recognizing some rational thickness of material to radius of gyration: developed in personal practice, a circular section 20 ft. in diameter ¼ in. thick, radius of gyration 85, "radii" 13½, to support a compression of 5,000 lbs. per sq. in. Inquiry among engineers and a review of practically all the literature on the subject availed me nothing; therefore I made a test on a circular figure of 1-20 size, height and thickness; that is, thickness was 1-80 in., diameter 16 in., height 57 in. and was agreeably surprised to note that the material in this form developed 7,000 lbs. per in. ultimate strength. (See Fig. 1.)

These examples are on circular figures where the circular element has to do with the ability of very thin material to resist compression. What of the plate in a rectangular compressive member? Someone has specified that it must be 1-30 as thick as wide. For want of other basis it has generally been accepted. The radius of gyration will modify and hold in check any disposition to use material of undue thickness, but what of thin plates? They are freguently used and surely of some value. Also thin plates in multiple with more or less efficient riveting, however, in no way forming a homogeneous whole.

As to the value of flat plates in compression, one or in multiple and the relation of thickness to width, we have no definite knowledge.

The suggestions apply the radius of gyration through the center transverse to a plate and limit the "radii" width of a plate to the "radii" length of built up member of which the plate is a constituent part; also applying the same method to projecting flange of shape material, limiting "radii" of same to ¼ "radii" of member. Further the "radii" of a lattice panel of a channel or a similar section rolled or built shall be no greater than the "radii" of the entire member.

These applications of the radius of gyration will produce results not materially different from practice in the average and usual member, but will allow thinner material as the "radii" of the member increases. The compressive formula presented in the suggestions, only works a reduction of compressive unit value when over 71 "radii"; hence the application of "radii" as indicating thickness of plate material will only apply as member is 71 or more "radii" in length. In members 71 "radii" and less plates will be 1-24 thickness of width.

Of proportion or percentage of shapes necessary to properly combine with plates, we have only suggestion from practice.

Columns of 100 "radii" will, under compression, yield by bending. The same column under a transverse load will also yield by bending and here we have evidence that compression and transverse load will develop *shear*, termed eccentricity by many writers, in all cases however it will be noticed that the eccentricity is arbitrarily arrived at. Of *shear* or proportion and relation of *shear* to compression, acting through the member, specifications are absolutely silent.

Practice shows *shear* to be well provided for by cover plates, tie plates and lattice as used on typical columns of medium size in box or laced members and does in all cases provide for 5% at each end of the compressive force acting through the column. This is the basis of analysis of both cover plates, stay plates or lattice as used on rectangular compressive members.

Many specifications in general use, have specified an ability in tie plates at the end of open lattice column to transfer 25% of the load across the column and is safe practice; this carried into the lattice would seem excessive, but surely somewhere between 5% and 25% will give safe results.

The proportions of shapes and plates and thickness, to width of plates and shapes in connection with shear, are vital ones in designing a safe compressive member, and undoubtedly have as much importance as the "radii" in determining the unit value of the material used.

It is hoped that investigation and research may be undertaken on the immediate relation of parts similar to those used in composite rectangular compressive members. We surely can gain knowledge from models at even 1-16 size tested to destruction at comparatively small cost.

To design to the accompanying suggestions, will show us difficulties in making a latticed compressive member of excessive size, both in the size of lattice and the connection of the lattice with the flanges. This leads to the very natural conclusion that when an extraordinary large section is to be built, box members will be used for the same reason that practice has forced the use of plate or box girder under somewhat similar conditions; that is, where considerable shear exists and a very shallow girder is a necessity.

The compression formula presented herewith does not limit the "radii" length a member may be built, but does reduce for increased "radii" very much more rapidly than formulas as usually written. It also limits maximum compression to ¾ tension. The particular formula was arrived at because it fairly fits, using 20,000 dead load unit stress, and the standard straight line formulas of the day, in its application to chord members and also for posts with modified unit stress.

Accompanying is an extension of the formula showing the relative position with the straight line formulas referred to, and Pin Bearing Formula on page 143 of the Carnegie Hand Book for 1903, and the further fact of having knowledge of tests on solid rounds 300 "radii," which also justifies the form of the formula. It is proposed to use this formula in all compressive members, because compressive members in a truss structure are only fixed by other compressive members subject to flexure from the same load.

I have noticed a tendency to use excessive unit stress in compression members of small "radii;" while it is a fact, tests of homogeneous steel in short lengths show an ability to resist compression equal to its ability to resist tension. It must not be overlooked that a compression member, however short, of any form used in construction, is a composite and not homogeneous body. It is entirely impossible to be certain of a reasonable uniform distribution of force over the entire section of a short member. Undoubtedly a member 100 "radii" is as reliable as one 5 with same load, because of want of ability to distribute the load uniformily over the short section and the further fact that a member 5 "radii" long is not likely to present conditions to successfully combine parts approximating a homogeneous member. Standard specifications allow only 6-10 of load on 100 as on 5 "radii" column.

The suggested limitations and relation of parts forming a mem-

ber. are derived from our experience and practice. In a rolled channel or beam at least 30% of the section is in the flanges, but 40% has been suggested as the pioper proportion of shapes in built channels or similar members. The extra 10% being in some sense to represent the proportion of shape in contact with the plates. The suggestion that multiple plates, building up webs of channels or similar sections of members, act individually is not sustained by practice, but it is hoped the suggestion may help to correct doubtful designing, considering it will present little or no difficulty and add nothing to cost.

In rolled or built channels or similar forms it is obvious that there should be a relation of "radii"; neutral axis both parallel and perpendicular to web. This proportion in practice is 1 to 5.8 extreme for rolled channels.

An extended review of specifications of American practice in bridge work indicates in the matter of unit stress, conventional relation between tension, shear, bearing and flexure of extreme fibre. The suggestion presented follow such relation. In attempting to express relations for parts forming a compressive member, it is necessary to take unit stresses in consideration, as well as formula for compression.

In the various standard specifications we find additions and exceptions in the application of unit stress, to be the rule and not an exception. More than fifty different unit stresses are specified in one standard specifications, both confusing and exasperating, in attempting to follow, and the cause of many misunderstandings and blunders in proportioning parts.

For the purpose of design, dead load only is positive. The load of wind may actually exist, but is entirely an assumption as to the exact amount. The live load is usually the principal one, but is an assumption in so far as occasion for changing unit stress.

It appears to me the maximum-minimum formula, also the quite common one of assuming dead load stress at *two* and live load stress at *one*, for main members is unfortunate in the fact of not caring for secondary members and details with that certainty of proportion and relation that seems desirable.

It may be doubted if the author of either of the methods suggested above can tell us where "we are at" when reversals of stress as in chords of a drawbridge, with further demand that compression and tensions stress shall be provided for separately and added to arrive at the section of a member. Surely it is unecessary, both the uncertainty and absurdity as illustrated in this case.

Assume a stress that we are willing to use for dead load and then assume a wind pressure that we would be willing to care for with the same unit stress and wishing a structure proportioned for a live load known as Cooper's E. 50. double live load, that is, assume a Cooper E. 100; with unit stress of 20,000 lbs. per sq. in., (or any other stress desired), we would have developed a balanced struc-

ture, undoubtedly the intention of the specifications though not fully specified.

A recent paper before an engineering society shows deficiency of standard specifications in that an increase of live load of only 25% developed in one member an increase of 166% in stress in no way provided for and in another member, a reversal of stress, where a reversal was in no way contemplated. It is obvious that the method herein proposed fully cares for all the problems of counters, under increased live load of 100%.

Suggestions herewith presented, attempt to express the proportion and relation of component parts of columns as derived from practice, to the end that the relation and proportion may be used to develop columns of any size with some hope of satisfactory results.

The writer in no way claims originality in the suggestions. The various points considered are well understood by engineers familiar with metal design and have long been a matter of discussion and interchange of thought one with the other. Am inclined to say that engineers have considered the points made here merely fundamental and directed by common sense, at least I know of no written presentation of the proportions. The suggestions may be unnecessary, but surely will do no harm.

The suggestions in no way having to do with quality of material or details of connection, but are intended to fill in where standard specifications seem to be lacking.

SUGGESTIONS OF PROPORTIONS OF PARTS FOR RECTANGULAR WROUGHT COMPRESSIVE MEMBERS FOR FRAMED STRUCTURES.

Unit Stress————————

Compression=Unit Stress, times

$$\frac{1\frac{1}{2}}{1 + \dfrac{L^2}{5000\ R^2}}$$

$$\frac{L}{R} = \text{“Radii”}$$

Compression, never to exceed ¾ unit stress.
Flexure, extreme fibre = 1½ times the unit stress.
Bearing = 1½ times the unit stress.
Shear = ¾ times the unit stress.
Tension = Unit stress.

The method of applying force shall be such as to distribute over the entire area of the member equally for each unit of the entire section of load. Force applied to the member only through the center of gravity, if necessarily otherwise applied, bending stress shall be duly considered in reducing the value of the material.

Compressive members composed of shapes or combination of shapes and plates, shall preferably have the least possible number of shapes and plates to form said member, and to be as definitely and firmly fixed by riveting together as practicable.

If an enclosed box, four or more plates and shapes, 25% of the entire area shall be of shapes; if with two or more shapes and two plates then 60% of the entire area shall be in shapes.

If a trough, one side laced, 33-1/3% of the entire area shall be composed of shapes.

If of two or more built channels or similar forms, two sides laced, 40% of the entire section of the members shall be of shapes.

If of four shapes and plates, laced on all four sides, 50% of the entire section to be of shapes.

Rolled or built channels or similar forms shall have a radius of gyration at least 1/5 as great when the neutral axis is parallel to the center line of web, as when the neutral axis is perpendicular to the web.

Pitch or panel of lacing shall be such that the "radii" of a rolled or built channel or similar section with neutral axis parallel with the web never need be less than 25 and never more than the "radii" of the member of which said channel forms a part.

Plates in webs shall preferably be no more than 24 times as wide as thick on members less than 71 "radii." On members 71 "radii" and more in length, "radii" through center of any plate transverse to length of member shall be no greater than "radii" of member. Shapes used with plates to form built channels or similar sections shall have flanges equal to 1/5 the width of said channels or similar member and said shapes shall have thickness of metal equal to "radii" transverse to shape through center of flange of 1/4 the "radii" of the member, 71 "radii" and more. On members less than 71 "radii", a projecting flange shall not bess than 1/6 as thick as wide.

If shapes or plates of lesser thickness than preferred thickness are used, then the area shall be reduced to equal Preferred Thickness divided by the square of the Actual Thickness.

Plates grouped together, surfaces in contact and riveted, shall not be assumed to support one another, that is, if each or any of the individual plates are thinner than the preferred relation, as indicated above, then the reduction for thickness shall apply as specified for a thinner plate.

Compressive members, box or with one or more open sides, shall be stayed on all such open sides by lattice and at the ends with batten piates.

Cover plates and lattice shall have the ability to care for——— per cent of the entire compression, as sheer at each end of member.

Batten plates to be placed as near as practicable to the ends of compressive members with sufficient rivets; moment of inertia of the group of rivets being considered to determine their ability to transfer shear. Shear of both ends, equal to double the shear at one end, shall be considered as an equally distributed transverse load over the entire length of the member with cover plates, batten plates and lattice in vertical plane. If of more than two channels or similar sections, connections of cover plates, batten plates, and

lattice shall have sufficient connection to the flange of the outer channels or similar shapes to transmit the entire shear.

Cover plates, batten plates and lattice in vertical plane shall also have the ability to sustain the member in a horizontal position acting as the web of a girder supported only at the two ends, or supported only at the center. For the purpose of this last investigation, the total weight of the member shall be increased by a ratio of 2½. Preferably lattice shall be of uniform proportions for the entire length of a member. From the stresses as indicated, lattice should be designated with limitations by compression formula for stiffness, also the connecting rivets to flanges with limitations for bearing, shear and flexure.

Lacing shall be of width not less than two diameters of the rivets used to connect the same.

Rivets may be spaced within 3 diameters and spacing shall never exceed seven diameters of the rivet either in longitudinal, transverse or diagonal directions. Neither shall the pitch of rivets ever exceed twelve times the thickness of the thinest material through which they pass. Rivets to be spaced not less than 1¼ or more than 4 diameters from the edge, except rivets in lacing, one diameter of edge. In all cases rivets to be spaced not more than 1½ diameters from an end.

Preferably rivets in single shear shall have diameter equal to the thickest material through which they pass.

EXTENSION OF SUNDRY COMPRESSION FORMULAS.

(a)—Cooper Chord Segments.................... $20000 - 90\dfrac{L}{R}$

(b)—Cooper Posts, Thru Bridges................ $17000 - 90\dfrac{L}{R}$

(c)—Cooper Posts, Deck Bridges................ $18000 - 80\dfrac{L}{R}$

(d)—Cooper Lateral Struts and Rigid Bracing.... $13000 - 60\dfrac{L}{R}$

(e)—Carnegie 1903, page 143, 2 Pin Ends......
$$\frac{20000}{1 + \dfrac{L^2}{18000\ R^2}}$$

(f)—Suggested—Unit Stress, say (20000) times
$$\frac{1\frac{1}{2}}{1 + \dfrac{L^2}{5000\ R^2}}$$

and compression never to exceed ¾ Unit Stress.

The following table shows valuations worked out for the preceeding:

L/R	(a)	(b)	(c)	(d)	(e)	(f)	L/R
5	19550	16550	17600	12700	19970	15000	5
10	19000	16100	17200	12400	19890	15000	10
20	18200	16200	16400	11800	19610	15000	20
30	17300	14300	15600	11200	19770	15000	30
40	16400	13400	14800	10600	18360	15000	40
50	16500	12500	14000	10000	17560	15000	50
60	14600	11600	13200	9400	16670	15000	60
70	13700	10700	12400	8800	15760	15000	70
80	12800	9800	11600	8200	14700	13150	80
100	11000	8000	10000	7000	12890	10000	100
120				5800	11110	7730	120
140					9570	6100	140
160					8260	4900	160
180					7120	4020	180
200					6210	3330	200
225					5350	2700	225
250					4480	2220	250
300					3330	1580	300

Discussion.*

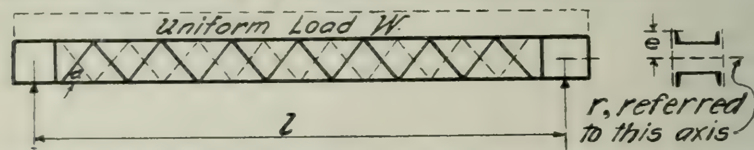
Mr. J. W. Schaub, M.W.S.E.: When we get to large members we shall probably have to resort to other methods than lacing for holding the component parts together, say by means of diaphragms so as to make the component parts act practically as a unit instead of relying on the lacing Such methods have been usd before—recently in the Forth Bridge, where cylindrical compression members were used. I think a rectangular member can be built just as well as a cylindrical member by this method.

Mr. A. Reichmann, M.W.S.E.: The subject of compression members is one which should receive the most earnest consideration of our engineers. Our knowledge of the action of tension members and their physical strength is quite well determined. I also believe that the more competent engineers thoroughly understand the proper design of compression members; however there are a great many engineers who do not give the compression members any further consideration after they have once determined their main sections.

It is not uncommon in buildings to have posts in the upper stories with large attachments carrying eccentric loads for which every detail of the connection has been very carefully worked out, but the posts themselves are not provided with the proper means of taking care of the bending; that is to say, the main members are not properly tied together with a web as they should be, but are inadequately tied together with lattice bars which have little ability to transmit shear. The specifications of the American Railway Engineering &

*The discussion of Mr. Horton's paper, was held the two evenings of Oct. 2, 1907 and January 22, 1908, and also includes sundry discussion sent in by letter.—*Ed.*

Maintenance of Way Association state that compression members shall be built concentric about the neutral axis, which has lead many less experienced engineers to make their top chords and end posts of truss bridges without a top cover plate, using lattice bars top and bottom. While this method of designing is good enough for top chords, it makes a very poor design for an end post which must transmit the total wind stress from the top chord to the masonry. While it is possible to make lattice bars sufficiently strong to transmit the shear due to the wind forces, nevertheless it is very seldom done. I believe that lattice bars should be avoided wherever possible, and that in a great many cases, lattice bars are used in compression members where it would not only be better but also cheaper to use a web plate. The function of the lattice bar in an ordinary compression member, where there are no additional eccentric loads, is to transmit the amount of shear to the main sections of the member equivalent to the reduction in unit stress from that ordinarily used, where the members are so short that flexture can be ignored, as is illustrated in the compression formula of the American Railway Engineering and Maintenance of Way Association. The unit stress 16000 represents the compression in the member before deduction has been made on account of its length. The term 70 l/r represents the deduction that must be made in the unit stress, to provide for the bending, induced by the direct stress. This bending may be assumed to have been produced by a uniformly distributed load W, the maximum shear of which shall be taken up by the lattice as indicated in sketch:



The amount of W can be found then by considering that it must produce a bending unit stress of 70 l/r. This is expressed by:

$$\frac{Wl}{8} = \frac{I}{e}(70\, l/r)$$

where I, is the moment of inertia of the section of the post, around the axis shown in sketch and e, the distance to the extreme fibre. Now $I = Ar^2$, where A, is gross area of section, and hence above equation reduces to: $\frac{W}{8} = 70\frac{Ar}{e}$ or $W = 560\frac{Ar}{e}$.

The lattice bars at the end have each a shear of ¼ W, hence the shear is $S = 140\frac{Ar}{e}$ and the stress, compression in one and tension in the other is $140\frac{Ar}{e}$ sec. a.

For 60 deg. lacing sec. a $= \frac{2}{3}\sqrt{3} = 1.15$ which would make the stress $= 161 \frac{Ar}{e}$.

It must be remembered however, that in most cases the load induces secondary stresses in the member, partly due to the connection of the ends of the member and partly due to the portion of the compression transmitted to the lattice bars, which in turn induces bending in the main sections of the member; for instance, if the compression member shown in Drawing A is reduced in length a certain amount for each panel of lattice bars, the lattice bars are likewise reduced this amount multiplied by the secant "a." It would therefore seem proper that in order to avoid having any lateral deflection of the compression member, due to the action of the lattice bars, that a tie be placed at the point of attachments of the latice bars to the main members as indicated by dotted lines in Drawing A. Possibly with the use of a formula somewhat along the lines stated above we might establish proper size lattice bars for various members. Owing to the fact that there are many uncertainties in regard to the action of the lattice bars themselves, I believe that in a theoretical formula as stated above great care should be exercised, and low unit stresses should be used for these bars. I would recommend from 6000 to 8000 lbs.

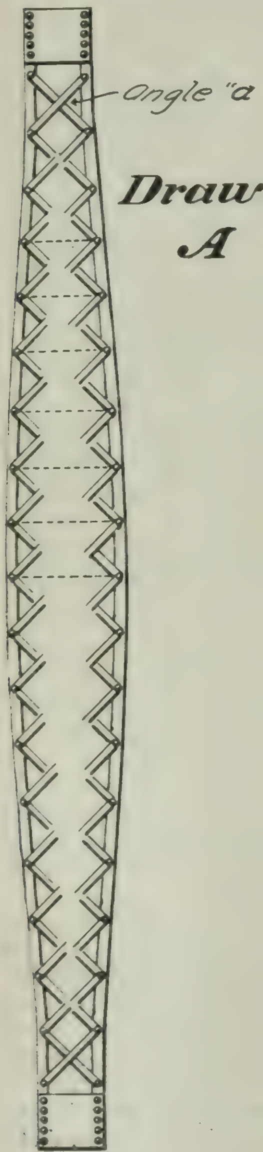
Another feature which Engineers should consider in designing their compression members is, that they are so designed that they can be completely assembled before they are riveted up, in order to get a good, straight and workmanlike job. This can only be accomplished in the larger compression members by the use of at least two rivets at the ends of each lattice bar and large members should also have a sufficient number of diaphragms in addition to the lattice bars to permit their handling without being distorted in the field.

What I have said above in reference to compression in the posts proper, inducing stresses in the lattice bars, applies with equal force to viaduct towers, which are built without horizontal struts. I believe that very few engineers realize the secondary stresses that are induced in their tower columns through the bracing where horizontal struts are omitted.

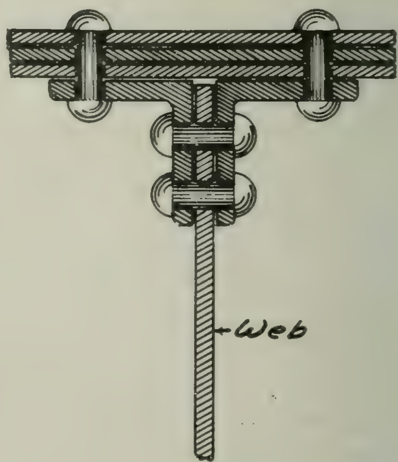
Another point where I believe we have been blindly following the foot steps of the past is in the use of the rivets connecting the horizontal legs of the flange angles with the cover plates of our plate girder bridges. The efficicieny of the rivets connecting the cover plates to the flange angles is increased as their distance from the center of the web increases. I therefore believe, that instead of having two lines of rivets connecting the cover plates to each horizontal leg of the flange angles in our plate girder bridges, we would get a stronger compression member by the use of one line of rivets, that is

where the cover plate is not too thin, which is hardly ever the case. This is illustrated in Drawing B.

Prof. O. H. Basquin, M.W.S.E.: I am interested in the subject of the strength of columns considered from the standpoint of eccentric loading. About nine years ago Dean A. Marston gave the mathe-



Drawing A



Drawing · B

matical solution (Trans. Am. Soc. C. E., 1898) for the maximum stress in a simple column under an eccentric load. This treatment corresponds exactly with the ordinary method of estimating the stress in a simple beam under transverse load. In 1901 Moncrieff (Trans. Am. Soc. C. E., 1901) reviewed all the available tests of columns from the standpoint of eccentric load. He showed that practically all columns tested had an eccentric parameter lying between the extreme values 0.15 and 0.60. The eccentric parameter is a pure ratio and is defined as ec/r^2, in which e is the eccentricity of loading, c is the distance from the gravity axis to the most stressed fiber, and r is the least radius of gyration.

This method of looking at the strength of a column has the great advantage that the curve representing this strength is a continuous function of the slenderness-ratio (l/r). Ordinarily one uses Euler's curve for large values of the slenderness ratio, while for smaller values we must leave the curve and follow one of its tengents in order to correspond with experiment. Now Euler's curve is simply the curve for which the eccentric parameter is zero. For large values of the slenderness ratio all curves of reasonable eccentric parameter lie very close to Euler's curve, but for smaller values of the slenderness ratio they lie well below Euler's curve and correspond fairly well with experimental results.

In the Engineering News for April 18th, 1907, there is an article in which are pointed out some easy methods of using formulas for columns under eccentric loads. In connection with this discussion upon the shear in columns, I wish to point out a rational and ready method of estimating the shear in a column under an eccentric load. After working out this method myself independently, I am the more bold to call your attention to it because this afternoon I noticed the same method given in the editorial columns of the last number of Engineering (September 20, 1907).

The method corresponds exactly with the method of finding the shear in a simple beam whose elastic curve is known. The elastic curve of the column is fairly well known, (see Tetmajer's Elasticitat und Festigkeit.) The second derivative of the displacement with respect to the longitudinal coordinate when multiplied by EI gives the bending moment at any section of the column. Since the column is practically straight, the shear at any section of the column by now be gotten by differentiating the bending moment with respect to the longitudinal coordinate. The maximum value of the shear will be at the end of the column so that the final formula is

$$S = P\frac{e}{r}\sqrt{\frac{p}{E}}\tan\frac{l}{2r}\sqrt{\frac{P}{E}}.$$

In this formula S is the maximum shear, P is the load, p is the unit load, l is the length of the column, and E is Young's modulus.

The expression contains the eccentricity e of the load. This should

be given an outside value by those who are familiar with the loading, the care used in fabrication, erection, etc., or a value may be taken from Moncrieff's study of column tests.

I trust that the engineering profession before so very long will come to this rational view of the strength of columns.

Mr. C. R. Dart, M.W.S.E.: It seems to me that the matter of shear in a great many columns depends somewhat on the end connections. I think that ought to be considered.

Mr. W. C. Armstrong, M.W.S.E.: I believe the question of the stress in a latticed member for excessively large sections, as given by some of the speakers, can be reduced by taking into account a longer tie-plate at the end. It is a question of transfer of stress from the lattice considered as a web, to the one member of the column considered as a flange, and this stress is transferred through the tie-plates at the ends and through the lattice bars. By an extension of the tie-plate it is possible to get a greater number of rivets for the transfer of this stress than by using an ordinary length of tie plate and filling out the rest of the column with lattice. This is simply a suggestion which I offer.

Mr. A. Von Babo, M.W.S.E. (by letter): As long as we use compression formulas which are functions of I, the moment of inertia or of r, the radius of gyration of the cross-section of the column, the latticing, or more generally the connection between the main parts constituting the column, should be of such strength and construction, that the full shear which may possibly be produced or come into play, if the moment of inertia of the column had to counteract bending actions can be safely transmitted Only in case the several main parts forming the column are rationally connected with each other have we the right to figure and to introduce into our column formula, the integral moment of inertia calculated for the entire cross-section as one body.

As this method of reasoning is generally recognized as being correct in case of plate girders when figured by means of the moment of inertia, why then should we allow and introduce in column formulae, which are based upon and contain the same kind of I as used in plate girders, moments of inertia that are figured and correct for a full connection, when the parts of a column are only slightly bound together.

In other words, I would say that a column, for which we use the column formula, should be so constructed that, if this column were to be used as a loaded beam by first being laid flat on one side and loaded and then turned 90 degrees around its axis and again loaded in the same manner as before, it would show the same strength against bending in both cases, or at least the strength that would correspond to the moment of inertia to be used in the column formula.

Mr. W. C. Armstrong (by letter): The scope of Mr. Horton's paper is so broad that an attempt to cover all the points raised in one discussion would not be profitable. I shall, therefore, confine my re-

marks to one point only, making that of the proper proportion of lattice bars and tie plates

The failure of the Quebec bridge has given an impetus to the study of column design that must surely result in great benefit to the profession. Immediately following this disaster there were many statements published in our technical journals to the effect that our knowledge of the action of compression members of exceptionally large size was not sufficient to enable us to successfully design such members. These statements created the impression that in some way compressive stresses acted differently in large members than they did in small ones, and it was suggested that only by means of tests on a very large scale could we hope to gain the knowledge necessary to design such large members.

Through the discussions and publications which have followed, however, I think that engineers have come to the conclusion that the fault in the detail design of this structure was not due so much to a lack of knowledge, as it was to the failure to thoroughly apply our available knowledge.

It is not to be denied that series of tests on full size members would add a great deal to our knowledge of column proportioning. It might lead us to modify our column formulas. But I doubt if it would add much to our knowledge of the proportioning of those details which only serve to bind together the component parts of the member.

Standard specifications have been very meagre in their reference to the proportioning of tie plates and lattice bars for connecting together the segments of a composite compression member, and generally have had nothing to say on this subject for members of more than moderate size; so that the engineer in designing larger members has been compelled to rely on his own resources for the proper proportions.

Column formulas do not aid us much in this matter. They are mathematical deductions based on ideal conditions. In all column formulas the length divided by least radius of gyration is the measure of lateral stability. But the radius of gyration is not a concrete quantity; it is simply a relation between the moment of inertia and the area of the section. The moment of inertia is only a geometrical property, not physical. It has nothing to do with physical conditions. It is the same for members of similar cross section, regardless of the material. It is the same for a composite member, regardless of how the integral parts are bound together. Therefore, the use of this geometrical property in the column formula makes it to a certain extent an expression of ideal rather than actual conditions of strength.

One of our technical journals in commenting upon this subject recently made the following statement:

> "In column calculations the lateral stiffness alone is involved, and it makes no difference whether or not the lateral web-system is strong enough to stress the flanges to their point of failure. Therefore as long as a complete web-system is present,

the full radius of gyration of the cross section around its gravity axis must be used in determining the length ratio."

From a strictly theoretical point of view this may be true. But I do not believe it will be accepted by engineers from a practical standpoint. For it certainly does make a difference whether the web-system has the strength to perform actual duty, or whether it is a mere tissue. A column seldom fails without flexure. It cannot deflect without shear. And shear cannot be resisted except by an efficient web-system. Therefore the ability to actually resist flexure is the element that should be the principal factor in determining column strength. If, then, the radius of gyration is made an actual measure of the moment of resistance, we introduce the physical conditions of the make-up of our column into the formula for strength.

It is true that if the fabrication is so perfect that the gravity axis is a straight line, and the column is centrally loaded, there is no tendency to deflect, and consequently no actual work for the web-system to perform. But this is a condition never realized in practice. There is always eccentricity of stress. It cannot be avoided, nor can it be even approximately premised. In addition to the eccentricity, whether designed or contingent, the member may be subjected to accidental shocks. If used in a bridge structure it may receive a blow from a derailed car, or be struck by some projecting part of the load, or by some object falling from a car. All these contingencies should be considered in determining the rule by which the web-system is to be proportioned.

This, then, brings us to the question: How shall we proportion the tie plates and lattice bars in order that they shall develop their proper strength considered as web members?

Generally these are fixed arbitrarily; but a few attempts have been made to deduce formulas and rules for determining the sizes required. One method is proposed in "Theory and Practice of Modern Framed Structures." Another was presented by Mr. Thos. H. Johnson, in Engineering News of September 26th, 1907. Each of these is deduced from the straight line formula, by using that part of the formula representing the stress due to flexure, and then assuming a load on the member considered as a girder supported at the ends that would produce an equal stress. The size of the lattice is then determined from the vertical shear caused by this load. The method in "Framed Structures" assumes a uniform load; while Mr. Johnson's assumes a center load.

Each method gives different results; those by the former being about three times greater than those by the latter, and both smaller than would be used in practice. As an example a column composed of two 15 in., 33 lb. channels with single lattice at 60 degrees would require that each lattice bar have a sectional area of 0.28 sq. in. by the "Framed Structures" rule and 0.09 sq. in. by Mr. Johnson's Each makes the size of the lattice bar vary directly as the sectional area of the column.

Another method is suggested in the paper presented by Mr. Horton, and is as follows:

> "Cover plates, batten plates and lattice in vertical plane shall also have the ability to sustain the member in a horizontal position acting as the web of a girder supported only at the two ends, or supported only at the center. For the purpose of this last investigation, the total weight of the member shall be increased by a ratio of 2½. Preferably lattice shall be of uniform proportions for the entire length of a member. From the stresses as indicated, lattice should be designated with limitations by compression formula for stiffness, also the connecting rivets to flanges with limitations for bearing, shear and flexure."

Still another one is from Mr. Henry S. Prichard, published in Engineering News of October 3, 1907; and is as follows:

> "The lattice bars shall be so spaced that each channel between lattice connections shall be stronger than the column considered as a whole, and their size shall not be less than would be obtained by treating the column as a lattice girder supported at the ends and loaded at the middle with a load equal to 3% of the total compression on the column."

The two last mentioned rules make the size of the lattice bars vary with the length of the column. By Mr. Horton's rule the size would vary directly as the length; while with Mr. Prichard's rule it would vary *inversely* as some function of the length. To illustrate with an example, assume a column composed of 2—12 in., 20½ lb. channels. Then, with a length of 25 r, the sectional area required by Mr. Horton's and Mr. Prichard's rules would be 0.08 sq. in. and 0.25 sq. in. respectively. If we take a length of 125 r, the sizes become 0.40 sq. in. and 0.12 sq. in. respectively. There is manifestly something wrong with the theory upon which one of these rules is founded, for they are diametrically opposite in effect. Mr. Horton's rule has one advantage in the fact that it provides better against the crippling of a long column by rough handling during manufacturer or erection, as it requires larger lattice bars.

In order to make a comparative study of results, and also to put in practical form the suggestion with which this discussion was opened, viz: that to make our column formulas applicable to actual conditions we must make the strength in the plane of the lattice some actual measure of strength in the plane of the webs, the following analysis is presented:

Let M=Moment of resistance to bending in the plane of the webs,
f=allowable unit stress in bending,
S=total horizontal shear, or flange stress due to bending in the plane of the lattice,
I=moment of inertia,
r=radius of gyration,
d=depth of channel or leaf composing column.

w = distance between rivet lines in lattice,
l = length of column,
A = sectional area of column,
s = axial stress in lattice bar,
Θ = angle of lattice with axis of member.

The fundamental equation for bending in the plane of the webs is

$$M = \frac{fI}{\frac{1}{2}d} \qquad (1)$$

Now if the column has the same resistance to bending in the plane of the lattice, we have $S = \dfrac{fI}{\frac{1}{2}dw}$ (2)

Assuming that one-fourth the entire shear is transferred by the tie plates, and the balance by the lattice, we have the

$$\text{Shear carried by lattice} = \frac{1.5\, fI}{dw} \qquad (3)$$

and since the maximum bending moment occurs at the center of the column, and is developed in a distance of ½ l we have the

$$\text{Shear per unit of length} = \frac{3fI}{dwl} \qquad (4)$$

Now the length of the lattice panel is w cotan. Θ, and the direct stress in the bar is equal to the horizontal shear divided by cos. Θ. Then if n = the number of bars per lattice panel, we have, by substitution in Eq. (4), $s = \dfrac{3fI}{ndl \sin \Theta}$ (5)

This would give a column practically as strong in the plane of the lattice as in the plane of the webs.

If we substitute in equation (5), f = 15000, I = Ar^2 and $d = \dfrac{r}{0.36}$ we have $s = \dfrac{16200\, A}{n \sin \Theta\ (l/r)}$ (6)

from which we see that the size of the lattice bar would vary directly as the area of the column and inversely as the length ratio. For single lattice at 60 degrees this becomes $s = \dfrac{9353\, A}{l/r}$, (7)

and for double lattice at 45 degrees it becomes $s = \dfrac{5728\, A}{l/r}$ (8)

In the table which follows, Fig. 4, a comparison is shown between the values given by equations (7) and (8) and those given by the various other rules previously mentioned. In order that the compari-

son be on the same basis a value of $l/r = 50$ was used in all cases, by substitution of which equations (7) and (8) become respectively

$$s = 187\,A \qquad (9)$$

$$s = 115\,A \qquad (10)$$

which were used in the calculation of this table.

The stresses given by Mr. Prichard's rule were calculated from the Gordon formula,

$$p = \cfrac{15000}{1 + \cfrac{l^2}{13500\,r^2}}$$

and the stresses from the "Framed Structures" and Mr. Johnson's rules were calculated from the straight line formula, $15000 - 47\,l/r$ which for $l/r = 50$ gives practically the same result as the above Gordon formula. The results are given for seven actual columns, the general make up and principal elements of which are shown in table Fig. 3.

No. of Section	Stress per lattice by Eqs. 9 and 10	Stress per Lattice by other rules				Size of lattice required by Eqs. 9 and 10	Size of lattice required by various Standard Specifications		Remarks
		Framed Structures	Mr. Johnson	Mr. Horton	Mr. Pritchard		Max.	Min.	
1	1450	670	210	310	850	1¼" × ¼"	2¼" × 5/16"	2" × ¼"	Single Lat. – 60°
2	2250	1040	320	580	1320	1½" × 5/16"	4" × 5/16"	2¼" × 5/16"	do
3	3700	1710	530	1150	2170	1¾" × 3/8"	4½" × 3/8"	2½" × 3/8"	do
4	6820	3140	980	3180	3980	2½" × ½"	L 4" × 3" × 3/8"	L 3" × 2" × 3/8"	Double Lat. – 45°
5	14140	6520	2040	6500	8240	L 3" × 2" × 5/16"			do
6	24610	11340	3550	13800	14340	3½" × 3" × 3/8"			do
7	58650	27030	8460	39800	34170	5" × 3½" × 5/8"			do

Fig. 3.

The sizes of lattice bars were calculated for a working strain of 15000 lbs. per sq. in. It is assumed that where flats are used they shall have a thickness not less than 1/40 of the distance between rivets for single lattice and 1/60 for double lattice. On this basis the following values were used for lattice bars in compression:

Single lattice at 60 deg., flats 6000, angles 9000.

Double lattice at 45 deg., flats 6000, angles 10000 for 2 leaf columns, 11500 for 3 leaf columns and 12500 for 4 leaf columns. The higher strains are used for the 3 and 4 leaf columns for the reason that the unsupported length of bar is shorter.

An inspection of this table will show:

1st. That the stresses in lattice bars given by the four "other methods" do not agree with each other.

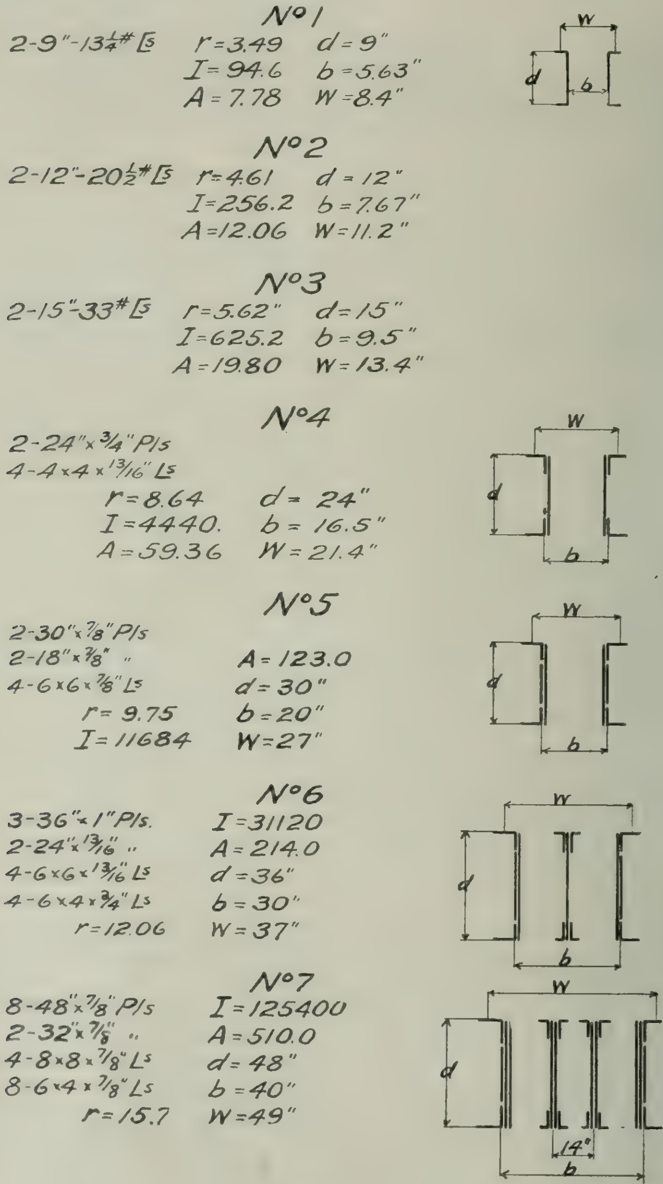


Fig. 4

2nd. That the sizes of lattice bars required by these rules would be much less than those required by our various standard specifications.

3d. That the variation with each other and with standard practice is so great as to preclude the use of all of these rules as practical guides.

4th. That the sizes of lattice bars shown in Column 7 of Fig. 4 as required by equations (9) and (10) correspond more nearly with the sizes required by our various standard specifications for columns of such sizes as the specifications apply to. Also that the sizes of lattice bars shown necessary for columns larger than are provided for in the ordinary specification correspond very closely with what are used in good practice.

The disparity between the sizes given in Column 7 and those in Columns 8 and 9 is more apparent than real, for the reason that Column 7 shows the actual sizes required for the calculated strength. But the size of rivet used determines the limiting sizes of these small bars.

It also develops from a study of this problem that the area of the lattice bars should vary directly as the area of the column section. This is not a condition of Mr. Horton's nor of Mr. Prichard's rules, but their methods are conventional and not based on any attempt, apparently, to analyze the stress conditions. With the "Framed Structures" and Mr. Johnson's rules, which are mathematically derived, it varies directly as the area only. The "Framed Structures" formula, approximately evaluated, can be reduced to the following:

$s = 86.6\ A$ for single lattice at 60 deg.

$s = 53\ A$ for double lattice at 45 deg.

which are approximately what would be obtained by making $l/r = 100$ in Eqs. (7) and (8). Mr. Johnson's formula may be written

$s = 27\ A$ for single lattice at 60 deg.

$s = 16.6\ A$ for double lattice at 45 deg.

which are approximately what would be obtained by making $l/r = 350$ in Eqs. (7) and (8). Both of these values of l/r are excessive, and the latter beyond the limit of permitted practice.

Now since both the "Framed Structures" and Mr. Johnson's formulas are mathematically derived, it must be assumed that their general form, $s = CA$, is correct. It therefore only remains to assign a proper value to the coefficient, C, in order to obtain a practical working formula. I believe equations (9) and (10) offer this result.

Objection may be made to the methods employed in their derivation, and it will be acknowledged that they are crude. It would be more logical, of course, to retain the variable factor l/r; but as this would require a different size of lattice bar for every variation of the length ratio, it seems better to adopt an average value for this factor and make it constant. Our formula then makes the column practically of the same strength in the plane of the lattice as in the plane of the webs for a length ratio of 50. For ratios less than 50, it has

less strength and for ratios greater than 50 more strength in the plane of the lattice than in the plane of the webs; but in all cases a more equal strength in each plane than would be required by the more exact methods.

It has been assumed in this discussion that the tie plates transmit one-fourth of the entire horizontal shear, or flange stress when the column is considered as a girder with the lattice as the webs. If the moment diagram is a triangle, as would be the case with a center load on the girder, the length of tie plate should be ¼ of ½ l or ⅛ l in order to transmit one-fourth of the total stress. With $l/r = 50$, the length of tie plate (L) becomes $L = 6.25\ r$. But $r = \frac{W}{25}$ (nearly). Therefore $L = 2.5\ W$.

If we consider the moment diagram a parabola, as would be the case with a uniform load on the girder, we would have for the length of the tie plate $L = 0.135$ of ½ l or .0625 l in order that it transmit one-fourth of the total stress. Reducing this in the same manner as above, we get $L = 1.25\ w$.

But as a matter of fact when a column is deflected by an axial compression the moment diagram is a sinusoid, a curve which lies between the triangle and the parabola. In this case we have $L = 0.16$ of ½ $l = 0.08\ l$ which reduced as above gives $L = 1.6\ w$. These three assumptions of loading are represented by Fig. 5.

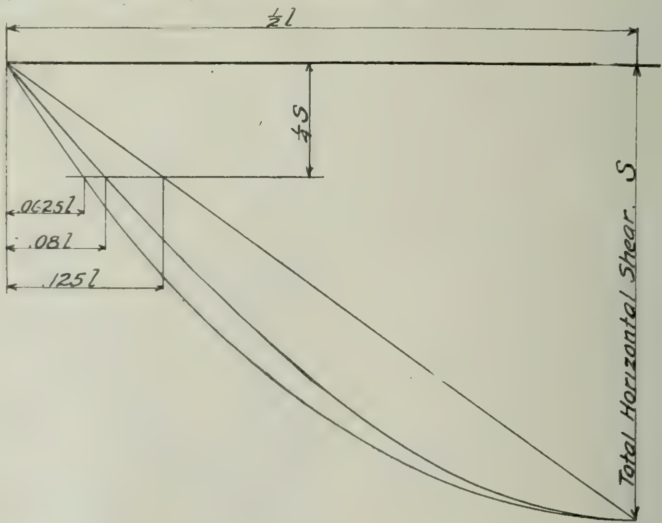


Fig. 5.

Examination of various standard specifications shows that the requirements for lengths of tie plate vary from the distance between rivet lines to 1½ this distance.

There is another point which has been brought out in the discussion of the Quebec Bridge failure which has been carried on in the technical journals, that is very important in connection with the detailing of compression members, and particularly in members of large cross section. It is the use of transverse ties, at right angles to the axis of the member, in conjunction with diagonal latticing. It has been mathematically demonstrated that the effect of such transverse ties is to cause the diagonal lattice bars to take a certain part of the direct compressive stress. With double latticing at an angle of 45 deg. and transverse ties at each panel point of the lattice it has been demonstrated that each lattice bar will sustain a compressive stress per sq. in. equal to 28 per cent. of the unit compression in the main section This is a serious matter. It was disastrous in the case of the Quebec bridge. For it seems quite probable that this unfortunate detail contributed largely to the final failure.

Mr. Andrews Allen, M.W.S.E.: Refering especially to Mr. Armstrong's discussion, the writer wishes to heartily endorse the proposition that in ordinary practice the lacing of compression members should have sufficient strength, both in section and connections, to develop the ultimate strength of the compression member, considering it as a girder with loads applied in the plane of the lacing. This method will give heavier lacing bars than would be obtained from calculations based on the lateral deflection of the column considered as a strut, and is based more on common sense and practical considerations than on fine mathematical deductions. We can only say that since a laced column may be subjected to a variety of unknown transverse forces such as impacts in handling, erecting and from accidents in service, imperfections in workmanship, etc., as well as the theoretical tendency to deflection under direct compression, we want to be sure that the column will never fail through deficient lacing. Very little extra metal will in most cases assure this. Then is it not the part of wisdom to make our lacing bars figure up to this requirement?

Those of us who agree in this theory will have room to differ on the method of applying it. Mr. Armstrong outlines what might be called a method of "horizontal shear," that is "horizontal shear" when the column is considered as a girder with loads applied in the plane of lacing. In practice one might figure the total stress in tension or compression capable of being carried by one segment dependent on the lacing in question, then consider this stress as transmitted to the segment by the rivets in tie plates and lacing from the end of the member to its center. This will give you a value for the horizontal component of each rivet from which the stress in the lacing can be easily derived.

It seems to the writer that this method is open to serious objection, from the fact that it fails to take into account the *rate* at which the flange stress is increased, and also because it would allow the use of a column like the "Gray Column" which has no diagonal lacing system at all. If we consider the column as a beam with the lacing vertical,

and place a concentrated load in the middle, the increment of flange stress will be constant from end to center. No matter how many rivets we may have in the tie plates in the end, they will not make up for a deficiency of rivets in the lacing bars any more than an excess of rivets in the end diagonal of a lattice girder will make up for a deficiency of rivets in the other diagonals. If we use a uniform load instead of a concentrated load, the total load that can be carried with the same unit stress in the segment will be greater and the flange increment will decrease from end to center giving a parabola instead of a straight line as the curve of flange stress. Here, in order to develop the column segments which we are now regarding as flanges, the rivets in the tie plates and lacing should be spaced more closely at the ends and further apart towards the center following the changes in flange increment, and their total number should as before develop the total flange stress.

Now it seems to the writer that there are two questions to be settled. First, shall we assume a centrally applied concentrated load or a uniform load (in each case, of course, of sufficient amount to develop the segment considered as a flange) and second, shall we figure the rivets and lacing from this load by horizontal shear (or flange increments) as proposed by Mr. Armstrong, or by vertical shear. As to the first, we are dealing with matters of pure assumption, and since the unknown transverse forces likely to be applied to a column are more apt to be concentrated than uniform, it seems to the writer that we are justified in assuming for purposes of calculation, a concentrated load in the center of the member applied in the plane of the lacing and sufficient in amount to produce the maximum allowable tensile or compressive stress in the segment. As to the second question, the writer believes for reasons given above that the "vertical shear" method should be used. This means that one half of the concentrated load should be regarded as the shear carried from each end and that the lacing bars and rivets should be proportioned to carry this load (the lacing bars the diagonal component and the rivets the horizontal component.) This method is very simple in practice, for instance, take a column consisting of two 12 in., 20.5 lb. channels 12 in. apart between centers of gravity and 20 ft. long, the area of each channel is 6.03 sq. in., one half of which or 3.015 sq. in. is taken care of by each lacing system. This will carry 48000 lbs. at 16000 lbs. per sq. in. of gross section, and a central concentrated load of 9600 lb. will produce this flange stress. The end reaction and shear is 4800 lbs., anl the stress in each 60 deg. lacing bar will be 5550 lbs. The horizontal component taken by the rivet will then be the same as the stress in one lattice bar or 5550 lbs.

As a matter of fact we are fast adopting, for important members at least, wide lacing bars with two rivets in each end, both because they make better struts and because they allow a member to be riveted up without unbolting any parts, also because they offer distinct advantages in maintenance as they have no recesses that cannot easily be

scraped and painted. We also eliminate lacing bars entirely wherever it is possible to do so. We would rather let all parts of a column section contribute to its working strength even if we are not able to use quite so high a unit stress. It is very frequently economical to use built "I" sections instead of laced channels and it is almost always economical to use a cover plate wherever possible. We regard both of these things as highly desirable from the standpoint of design, maintenance and manufacture.

Lacing bars are dead members and should be avoided wherever possible; when it is necessary to use them, the writer believes they should be very liberally designed.

Mr. F. H. Bainbridge, M.W.S.E. (by letter): A paper on this subject by such an experienced, original and successful designer as Mr. Horton would excite great interest at any time. In the light of recent occurrences and the extended criticism of them this interest is further accentuated.

A metal bridge column it is true is a composite member, not homogeneous, and so is the bridge itself, but the elements of a bridge can be analyzed individually, and so can the elements of a column.

It will be generally agreed that experimental tests on the strength of composite metal columns are desirable; but the statements which have repeatedly been made of late that we know next to nothing about the strength of composite columns, and that no designer, however competent, can feel any certainty in this field, are entirely unwarranted. The method to be pursued in the experimental tests should be that used by the Austrian Society of Civil Engineers in testing elastic arches. They determined the strength of the arch analytically and proved by their experimental tests not that the mathematical investigation was true, but that it was applicable in practice to elastic arches. An experimental test on a composite metal column would of itself prove next to nothing, not even so much as that another column, an exact duplicate in accordance with general shop practice, would act in the same manner. Mathematical investigation of the results to be expected from the inaccuracies of shop practice is all-important, even in the design of the experimental column. Now the mathematical theory of the elastic arch is intricate and involved: the mathematical theory of the elastic column is simple and obvious. The main difficulty to be encountered is the determination with accuracy, of the inaccuracies of the shop work on the column.

In a properly proportioned column, made with absolute accuracy with respect to shop work, the stress in the lattice, within the range of the elastic limit of the column will be an exceeding small fraction of 1% of the stress in the column.

Fig. 6 represents, in an exaggerated scale, the distortion in a mathematically accurate elastic composite column within the elastic limit. The dotted lines show the position after distortion. The lacing is double and at an angle of 45 deg. with the axis of the column.

A mere inspection of the figures show that the stress in the lacing

will be small—at the center of the columns practically nothing. The practice of placing additional lacing at right angles to the axis of the column, as A-A in the figure, is to be condemned.

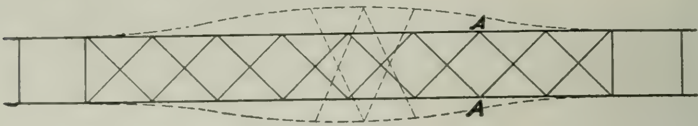


Fig. 6.

The tendency of such lacing as A-A is to maintain the segments at a uniform distance apart throughout the length of the column, producing a unit stress in the diagonal lacing, which is a considerable percentage of the unit stress in the column, and inviting the formation of a reverse bend in the column when not mathematically accurate in construction, the worst possible position both for segments and lacing.

Due to this faulty construction there would be, on the large lower chord sections of the Quebec Bridge, a stress in the diagonal lacing, assuming 20,000 lbs. per sq. inch in the main column, of 14,000 lbs. total, or 11,670 lbs. per sq. inch on each of the two ⅞ in. rivets in the ends of the diagonal lacing, from this cause alone.

I take exception to the statement of Mr. Horton that two or more plates forming the sides of a compression member, properly riveted together in accordance with conventional rules, are not mutually supporting. The matter can be determined by a simple experiment, though in my mind there is no doubt about it: Rivet several plates together; load them as a beam supported at the ends, and test to destruction. If the deflection corresponds to a beam of the depth of the added thickness of the plates, as it surely will, the plates are acting together; otherwise not.

Those who have had experience with Wakefield sheeting, consisting of three planks nailed together, will recognize that the stiffness of this sheeting is that of three planks forming a composite beam of a depth equal to the sum of the thickness of the planks. Also, if we cannot consider that two or more plates forming the sides of a compression member are mutually supporting, we must entirely give up the use of cover plates on the flanges of plate and lattice girders, where conditions, due to the increment of shear from the inner to the outer plates are more severe.

Experiments by the German government show that the outer flange plates of a plate girder within the limits of usual practice do not loose any considerable portion of their effective strength

Mr. Horton's proposal to adopt for compressive unit stress an intensity only ¾ as great as that for tension, seems to me to be based on unsound reasoning. The fact which he states, and which we may accept as substantially true, that there have been a considerable increase of failures in compression members and very few in tension

members, simply proves that incompetent designers have been abroad over the land. Anyone with a knowledge of simple arithmetic and a specification can proportion a tension member properly; while to proportion a compression member so as to develop the maximum strength of the material requires trained intelligence and a knowledge of higher mathematics.

It is a pretty well established fact that repeated applications of tensional stress within the range of one-half the elastic limit and the elastic limit, cause a reduction in the ultimate strength of the material, while applications of compressive stress under the same limitations do not. The corollary to this is obvious, that in a tension member which is to be subjected to an indefinite number of applications of tensional stress the unit stress should not exceed one-half the elastic limit of the material. Established practice places the unit stress for compression at the same figure, for reasons as stated in Mr. Horton's paper.

In the Lehigh Quarterly, June, 1891, Mr. H. S. Prichard proposed to proportion lacing of compression members for a load equal to 3% of the total stress in the column, treating the column as a lattice girder supported at the ends and loaded in the center. This conclusion was based on the theoretical analysis of the effect of the inaccuracies of shop work, more particularly the imperfect parallelism and squareness of the two milled faces of the column. This rule found its way into a few specifications but was generally considered excessive. On the heaviest lower chord section of the Quebec bridge, the lacing as proportioned by the method mentioned above has a strength equal to 0.2 of 1% of the stress in the column. Mr. Horton proposes for the lacing a strength of from 5% to 25% of the stress in the column without stating exactly how the proportioning is to be done. For large sections where great care may be assumed to be taken in the manufacture, I think the Prichard requirement is excessive and that for sections of from 100 sq. ins. to 1000 sq. ins. lacing proportioned for from 2% to 1¼% of the stress in the column is ample. Where a cover plate is used on one side of the column the lacing may be made of still smaller proportions. The requirement mentioned by Mr. Horton, that the lacing should have sufficient strength to carry the column when supported on its side at the center is obviously needed to prevent injury in handling.

The rivets at the ends of the lacing are the vital feature. Inasmuch as the stress in the lacing is due largely to distortion, it follows that the total stress in the lacing will be proportional to the sectional area of the lacing bar to a large degree. Hence the strength of a lacing bar should never exceed the strength of its riveted connection.

The standard specification referred to by Mr. Horton, which for an increase in live load of 25% develops in a member an increase of 166% in stress, is a poor standard. The specifications which use the impact formulas of Messrs. Schneider or Prichard amply provide for such contingencies by requiring that where live and dead load stresses

are opposite in direction, provision shall be made for an impact of 100%.

The practical effect of the Schneider and Prichard impact formulas is to provide for an increase in loading of 50% and a further allowance which approximates in amount the effect of impact as determined by experimental observation with the extensometer. Following the method proposed by Mr. Horton, the same result could be arrived at by assuming in place of the Cooper E-50 loading, a Cooper E-75 loading, and adding impact to the amount determined approximately by experiment. This method, however, is open to the psychological objection that it would be difficult to convince any railway management that provision for such an engine as Cooper's E-75 was necessary.

Inasmuch as the Cooper E-50 engine is right at the limit of the carrying capacity of the rail it would seem that provision for 50% increase in loading will prove to be ample unless the rail makers greatly improve the quality of their product by the use of nickel or some other alloy.

Of the two well known impact formulas, the Schneider and Prichard, I prefer the latter, as it makes a reduction in impact for ballast floor spans, while the Schneider formula requires the same percentage of impact for all spans of the same length, no matter what the dead load may be. Specifications based on the use of impact formulas are not open to the objection which Mr. Horton urges; that is to say, a great multiplication in the number of unit stresses. There is practically only one unit stress for tension, one for compression, one for shearing and one for bearing. Exceptions to this are the provision for combinations of stress, which are not often operative.

President Lowcth: A great many full size tests of iron and steel columns have been made and the reports are in print, but are scattered through the various technical and society journals running back over a good many years, are not readily accessible, and have been more or less lost sight of. It would be very desirable to compile all available test of metal columns together on one common basis, so that conclusions might be drawn from them. A great many of these tests have been made on the large testing machine of the United States Government at the Watertown arsenal, and are reported in the various annual reports of the tests made on this machine, and while the column tests are reported in detail, comparisons of the several tests, and conclusions therefrom, are rarely made, and for this reason, doubtless, these tests have not influenced engineering practice as fully as their value would warrant.

Judging from the discussion so far, there is a large variation of opinion. One speaker thinks two or more plates riveted together are worth only what the individual plates are, or but little more; another, that they are worth as much as a composite plate. I understand Mr. Bainbridge holds that Mr. Prichard's rule for determining the size of lattice bars, by assuming a load at the center of the mem-

ber of 3 per cent. of the actual load, is too much, while Mr. Armstrong suggests that we double it. The remark has been made that we should avoid lacing wherever we can, while the speaker thinks a symmetrical column section of two webs laced on the opposite sides, as in the common type of vertical posts in trusses, may be often a much stronger section than that made up of plates on three sides and lacing on the fourth side, as in the common type of truss top chords. This illustrates the wide range of individual opinion, and the desirability of more practical data for definitely determining the best and most economical proportioning of metal columns.

Mr. Armstrong: I think an explanation of the difference between Mr. Bainbridge's and my estimates of the sufficiency of the Pritchard formula may be found in the fact that we look at it from different standpoints. If it is compared with either the "Framed Structures" or the Johnson formula, an examination of the table, Fig. 3 will show it provides for larger lattice than either of them; therefore larger than are actually required for the stresses produced by direct compression only. But if compared with equations (9) and (10,) it will be seen to give results but little more than half as great.

President Loweth: Do you think the compression member ought to be as strong in the plane of the lacing as in the plane of the other members?

Mr. Armstrong: I think it should be practically so, except for very short or very long members, regardless of theory. There is no use in refinement of calculation, however, in this matter.

President Loweth: Will the lacing shown in your table meet that requirement?

Mr. Armstrong: Yes, for a length of 50 times l/r

President Loweth: When a boy the speaker was sometimes told it was better to send one man to mill than two boys. He has made it a rule to apply this maxim in the designing of steel structures and to use two instead of four, and four instead of six members, wherever practicable, so as to simplify the design. The rule applies particularly to built up compression members, where webs should generally not exceed two, and these be made up of one rather than two or more plates. But unfortunately the steel bridge designer has certain limitations of rolling mill and shop facilities which he must keep in mind; material of the desired quality can be obtained only in certain limiting dimensions, and the maximum rivet diameter generally practicable does not exceed seven-eights of an inch, where frequently a larger size would be desirable. With the increasing weight of modern railroad bridges, these and other restrictions, compel multiplicity and complication of details, and force the designer to make chord sections with web members of two, three, or perhaps more, plates more or less inefficiently tacked together with small rivets. The speaker trusts these manufacturing limitations may be soon removed.

Mr. Reichmann: Suppose you had a plate 54 by 2¾ ins., how could you get it from the mills?

President Lowcth: That is one of the limitations the designer has to contend with, which forces the undesirable combination of two or three thinner plates.

Mr. Horton: I suggest 54 by 2 ins. They can be of that size.

Mr. Reichmann: What quality of material?

Mr. Horton: Any quality you choose to pay for.

Mr. Allen: I wish to make one other remark along the line of the Chairman's observation,—that one of the difficulties in the present situation is from the failure of the shops and mills to keep up with the requirements of modern designing. I want to endorse that statement absolutely. One of the things I noticed in the Quebec bridge last year, without having any thought at that time that it would fail, was the disproportionate appearance that Mr. Horton has so strikingly called attention to. In that case there were members with hundreds of square inches sectional area, riveted with ⅞ in. rivets of maximum grip, and composed of metal of commercial thickness as used in ordinary structures. Who would think of building up armor plate in this way? We certainly would not countenance this method with proportionate dimensions in small structures. We must come, some day, I think, to the question of building our large bridges with specially constructed machinery, and with plates and rolled sections heavy enough to give a properly designed member; drilling the metal from the solid and using rivets of a size we do not use commercially at the present time. It is the American way to extend the methods that we have, to data that we have not;—as Professor Hatt has said, to exterpolate and not interpolate. We must learn some day that our monumental structures must be built, not as the English have built them, but at least with the full recognition found in their practice that such structures are beyond the limits of ordinary bridges.

Mr. Reichmann: I believe the largest rivets being driven are 1½ or 1¼ in. diameter.

President Lowcth: More or less prominence has been given in certain technical journals to the statement that there are not enough data available to engineers of the strength of large steel compression members to warrant the construction of a bridge as large as the Quebec bridge. It appears to the speaker that statement is not justified, as he thinks there are ample data available for the safe design and construction of a structure even larger than the Quebec bridge. As to the sufficiency of the data for ultimate economy in design, that is another question.

Closure

Mr. H. E. Horton: As the discussion has indicated some misunderstanding of my suggestions as to the amount of shear, lattice on a column should be able to sustain, I wish to be understood as recommending lattice on a compressive member to carry a shear of 10% of the compression, computed as a distributed load over the column, or 5% of the compression computed as a center load or in the column

that the lattice shall have the ability in a vertical plane, to carry the member with not to exceed 8000 lbs. unit stress when supported at the extreme ends, or when only supported at the center.

Am pleased to note that Mr. H. S. Prichard, as early as 1891, called attention to the necessity of considering shear in the column in proportioning lattice. As previously stated, it has been for as long a time a matter of common understanding among designers, as the only rational method.

My thought is more and more centered on the fact that the composite compressive member has a largely reduced value in comparison with a homogeneous one. I am also more and more certain, that a member of relatively thin plates secured with a few tack rivets, act as independent rather than as a whole. I have made the experiment. Physical tests are a necessity in advance of analysis, to point the way.

Mr. C. P. Buchanan's records of tests, appeared in the Engineering News of December 26th, 1907, is of 19 actual members as actually built for use in structures, covering a period of 18 years, 12 being of iron and 7 of steel. As I said on another occasion; the first noticeable thing is that radii length has no significance; in fact members 83 "radii" were as strong as any tested and much stronger than many under 40 "radii," and members of 97 and even 120 "radii" were a good average in the whole group of tests.

The average ultimate strength of seven steel columns is 31,900 lbs. to the sq. inch. The average crippling strength is 23,800 lbs. per sq. in. The average elastic limit 19,700 lbs. per sq. inch.

The ultimate strength, crippling strength, and elastic limit, in the above tests as reported, indicate a value scarcely more than 50% of the value of steel in tension. This is startling with our knowledge of specifications using steel in short radii lengths for the same stress as in tension. I tabulate Mr. Buchanan's tests as follows:—

Average Buchanan's Tests.	$\frac{l}{r}$	Average of T. H. & J. B. Johnson Formula, Crippling Load	Actual Crippling Load	Per Cent
4 Tests "Z" Columns............	96	28,537	21,700	76
15 Tests Troughs & Channel Cols...	43.6	33,125	20,730	62

From the photographs of the members after tests, it is shown that four "Z" bar column struts, yielded as a whole by flexure. The fifteen other members all yielded by some order of wrinkling or failure in individual parts. It is further noticeable that the section of the "Z" bar column were much thicker relatively. It is clearly apparent that compressive members which fail by wrinkling, fail at less load per unit than those that fail by flexure.

The suggestion that compression be limited to ¾ tension has been questioned and yet the tests above referred to, indicate scarcely more than a 50% value as compared with tension, either in ultimate

strength, yield point, crippling strength or elastic limit and these averages are from actual examples of actual practice and are the most comprehensive ones that have ever come to our notice.

The failure of the lower chord compressive members at Quebec referred to, failed as we understand, at about 18,000 lbs. to the inch. We believe that it is possible to design a member of 40 "radii" that will not fail under double this, or 36,000 lbs. to the inch and yet we have not an ultimate strength of 75% of the ability of the material in tension, but in fact only 60%.

My conclusions are:—

1st.—While the radius of gyration may be useful in investigating a very slim, extremely long column, it has no practical use in the problems met with in a large majority of compressive members, in actual practice.

2nd.—The connection of parts and the proportions of the cross section have more to do with the value of material in compression than every other element.

3rd.—Do not attempt "Leaning on the sustaining infinite", but use the "Rule of Three" and your common sense, and never allow more compression on a composite member than 75% of your tension.

4th.—It is the Physical Compression Member, we must consider, rather than the compression formula.

ELECTRIC ELEVATORS FOR HIGH BUILDINGS

By John D. Ihlder, M.A.I.E.E.

Presented January 10, 1908.

The evolution of the modern office building from the moderate heights of a few years ago, to structures of over 40 stories, and with no limit of height in sight, has brought out a new type of elevator which is especially suited for high rises and great speeds. This is the *Gearless 1:1 Traction Electric Elevator*. The high class office building elevator service was controlled, until recently, by the hydraulic elevator, principally of the vertical type, which gave excellent serice for the moderately high buildings of a few years ago.

Since 1890, when the *Direct Connected* Electric Elevator of the *Worm Gear* Drum type entered the field against the hydraulic, which was in almost absolute control at that time, it has gradually superseded the hydraulic, beginning with light duty, slow speed service, until it absorbed almost everything except special duties and high class office building service.

Several attempts were made with special electric machines to conquer the office building service; but after some apparent success these machines did not realize expectation.

From the earliest development of the electric machine there was the desire to do away with the gear, which the high speed motor required, but the gear had one advantage: The power consumed in it is to a certain extent a blessing in disguise, since it makes the machine safe against a runaway. With the abandonment of the gear it becomes essential to have a control device and safeties that will assure a safe operation, and it is probably due to the lack of a reliable controller, more than to any other cause, that designers did not push a gearless machine earlier. As soon as a really reliable system of control was assured the highly efficient gearless machine came in to stay.

After an attempt at a compromise, which substituted a multiplying rope device for the gear, in order to keep the motor speed as high as possible, for the purpose of reducing the size of the motor, it was found that the simplest possible construction was the best, and this has now become the standard. It consists in a motor with a traction sheave mounted on the armature shaft, around which the driving ropes are carried. The car is suspended on one end of these driving ropes, and the counterbalance on the other end. This gives a half turn of contact between ropes and sheave, which is sufficient for some duties, and answers for most if special grooves are turned in the sheave to bind the rope. Such special grooves are however liable to cause extra wear on the ropes, to avoid which it is generally best to

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*In the absence of the Author, due to illness, this paper was read by Mr. H. Russell Smith, Engineer of the Otis Elevator Co., in Chicago.

carry the driving ropes over an idler and a second time over the driving sheave, giving thereby *two* half turns on the driver, which provides sufficient traction, with *round* grooves, carrying the ropes without binding, for all practical loads as they occur in office building service. Tests show that this roping will carry, without slipping, 50% more load on the taut side than on the slack; thus a car weighing net 3000 lbs. can be loaded with 3000 lbs. of live load if it is provided with a counterbalance of 4000 lbs.

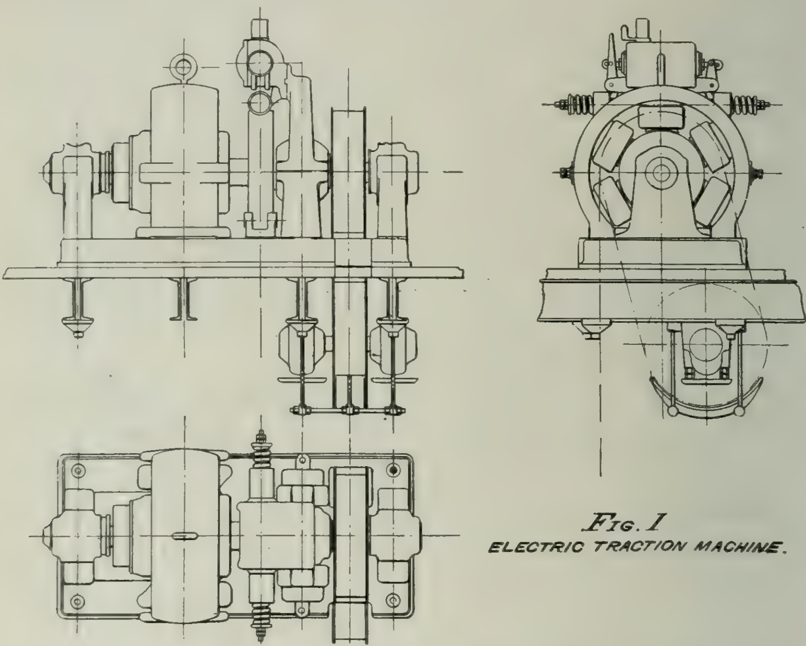


FIG. I
ELECTRIC TRACTION MACHINE.

This 1:1 Electric Traction machine thus consists of a motor carrying a driving sheave and an idler sheave, with ropes attached to car and counterweight, and if the machine is mounted over the hatchway no other sheaves whatever are needed, since by shifting the idler to one side or the other the driver and idler can generally be arranged in such a position that the ropes will lead directly to car and counterbalance, so that the idler answers the double purpose of giving an extra half turn on the driver, and also of giving the proper lead to the counterbalance ropes.

In order to give the necessary factor of safety against the breaking of ropes, from four to six ropes are generally used. In Fig. 1 is shown a machine for overhead position with idler placed to one side to give proper lead for the counterbalance ropes, while Fig. 2 shows a machine placed in the basement with idler mounted directly on the machine. The roping device is shown in Fig. 3. The rope or chain

from the bottom of the car to the bottom of the counterbalance, is used for high rises to balance against the shifting weight of the hoisting ropes.

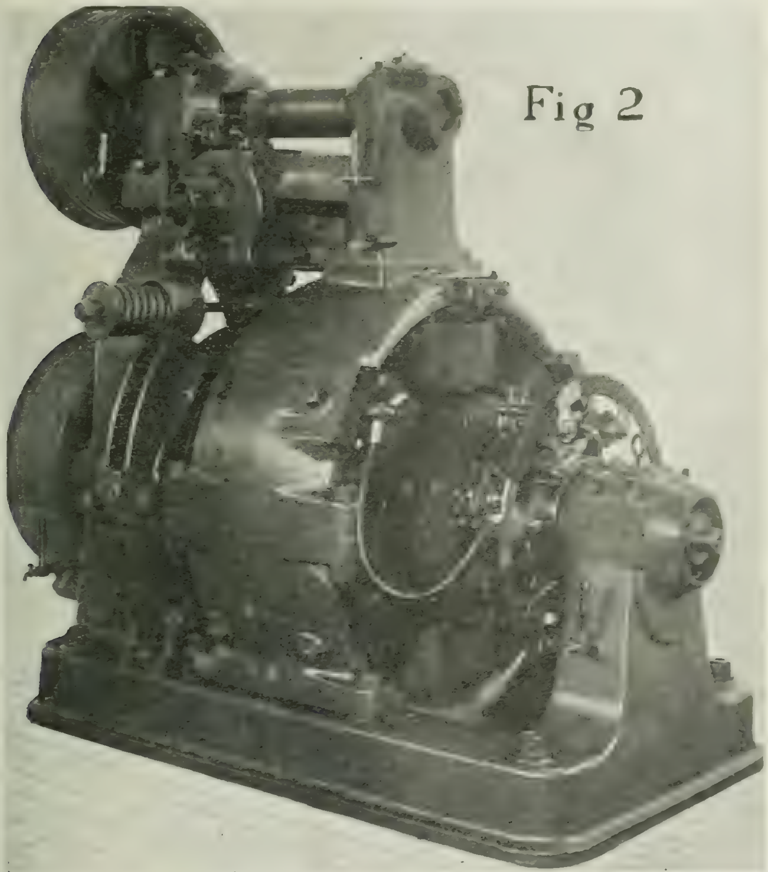


Fig 2

A number of special roping devices have been proposed and some have been patented, which are more or less useful to cover particular requirements. Where it is desired, for instance, that the size of the motor shall be reduced at the sacrifice of higher speed, the driving rope may be run at a higher speed by using reduction sheaves for the car and the counterbalance, the same as is done on the usual tackle. If applied to an elevator, such reduction sheaves must be arranged to occupy as small a space as possible in the hatchway, and to use only one set of counterweight guides. This is accomplished by using an extra overhead sheave, bringing one reduction sheave from overhead to the top of the counterbalance, and the other reduction sheave

to the bottom of the counter balance. It is at once apparent that any higher reduction than 2:1 can readily be made, but it will generally be found that the saving in cost at the motor end, due to its smaller size and higher speed, is more than offset by the cost of the reduction sheaves in the hatchway. Also the high speed of the ropes, and the attention which it is necessary to give the hatchway sheaves, make this type not nearly as attractive and advantageous as the direct drive machine.

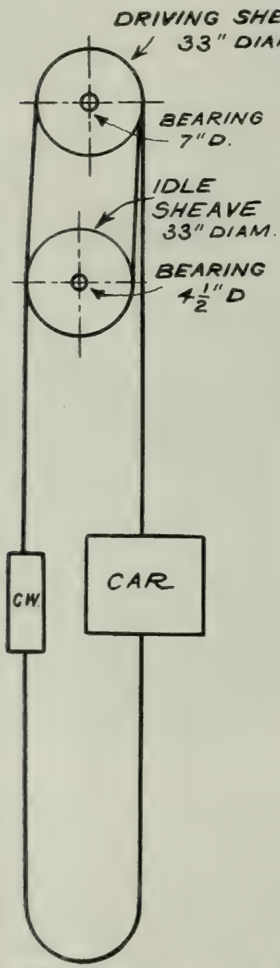


FIG. 3.

ROPE DIAGRAMS

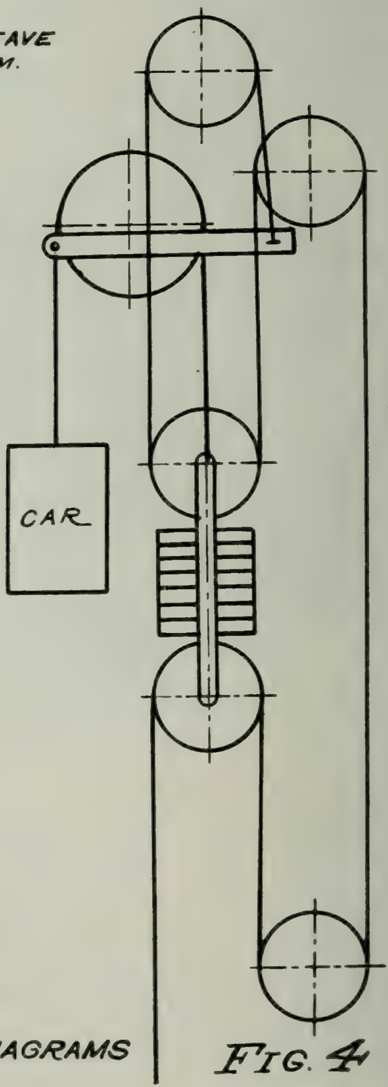


FIG. 4

Should the loads be of such unusually large variation that the standard two half turns are insufficient to give the necessary traction, more turns may be taken, or a special roping device can be used which increases the traction as the load is increased. This is shown in Fig. 4, which shows a 2:1 drive with overhead sheaves so arranged that the weight in the car produces additional tension on the traction rope. The car rope is carried over a sheave mounted on a movable platform, hinged on one end, the tension rope being attached to the other end of the platform. As the weight in the car increases, the moving platform increases the strain on the tension rope. Consequently the heavier the load the greater will be the traction of the driving sheave.

For the general requirements of high duty machines, none of these special devices with their resultant complications are however needed, and it is well that this is the case, since the great advantage of the machine is its simplicity. It is reduced to the least possible parts, and the principal part of the machine (the motor) being of ample size, and running at a speed of about 60 revolutions per minute is subject to a minimum of wear, so that in addition to its other good features it may safely be assumed that it will have a long life and small repair bills.

The ropes used are preferably ⅝ in. in diameter, which allows the use of driving sheaves of from 30 to 40 in. diameter.A driver of 36 in. on a motor making 63 revolutions per minute gives a car speed of about 600 ft per minute. A motor of this kind, for a full load running duty of about 35 H. P. can readily be made to give as high an efficiency as 87%, and over 80% for a range of 6 to 40 H. P. This comparatively high efficiency for the size of motor is due to the absence of iron losses, which are vanishing on account of the slow speed. Copper losses and the mechanical friction of the bearings are higher than in the small high speed motor, but it will be readily seen that the copper losses can be reduced, if desired, by making the motor somewhat larger, allowing more space for copper. The characteristic here shown compares favorably with the usual high speed elevator motor, and it will probably be found that for commercial requirements it will answer the purpose, the increase of first cost offsetting the gain in efficiency of operation for a larger and more efficient motor.

Whether the 1:1 Traction Electric Elevator will permanently take the place of the established hydraulic for high class office building service, depends on the ability to show that it is as safe as the hydraulic, and more economical and efficient in operation. A study of the machines installed will enable us to form a fair judgment on these points.

The safety of the machine depends on the motor, the method of control and auxiliary safety devices.

The motors used have been either compound wound or shunt wound. If compound wound the series field is used for starting only, and care is taken that it is effectively short-circuited before full

speed has been attained, so that under *all* conditions a shunt wound motor is used for the *running* duty; and shunt wound motors will run with only moderate variation of speed from full load up to full load down. The motor therefore gives in itself a good speed regulation.

The controllers that have been used with these machines are of the magnet type, where a small switch on the car controls a number of magnets, which, by opening or closing contacts, establish the circuit to the motor and its auxiliary resistances. One type of control is shown in diagramatic form in Fig. 6. Its principal parts are:

Potential Switch.
Reversing Switch.
Fast and Slow Speed Magnets.
Accelerating Magnet; and
Load Magnet.

The reversing switch makes and breaks the current on its upper contacts and leads the current in the proper direction to the armature through its bottom contacts. The fast and slow speed magnets allow the operator to run at full speed or reduced speed, and at the same time graduate the current when starting and stopping. The accelerating magnet with its multiple of armatures, accelerates the car automatically to full speed by short-circuiting the starting resistance as the speed and electro-motive force of the motor increase; the spool being connected to the motor armature magnetizes the core of the magnet in proportion to the electro-motive force of the motor armature; and the magnet armatures being adjusted to different distances from the core, will be attracted one after another as the magnetization of the core increases. The short-circuiting of the starting resistance and the series field is therefore absolutely automatic, independent of the operator, or of any mechanical dashpot.

The load magnet with its series of armatures establishes a current in parallel to the motor armature. This circuit preferably contains an extra field winding of the motor, which answers the double purpose to increase the magnetization, and by its inductive effect, to prevent a sudden rush of current, as the different steps of the operation are made, giving a smooth change of speed to the car.

The load magnet fills the important requirement to stop the car automatically at the top and bottom limits of travel for all loads within a limited distance. This is accomplished by making the automatic stop device operate in three steps. As the car approaches the limit of travel, a switch in the hatchway is opened and thereby a certain amount of resistance is placed in series with the armature and the circuit in parallel to the armature is closed, containing preferably, as stated, an extra field coil. This operation reduces the speed of the motor to a variable amount, depending upon the load in the car. A heavy load down, will produce a small reduction, and a light loao down a great reduction in speed. As soon as this variable speed has had time to establish itself the car comes to a second switch in the

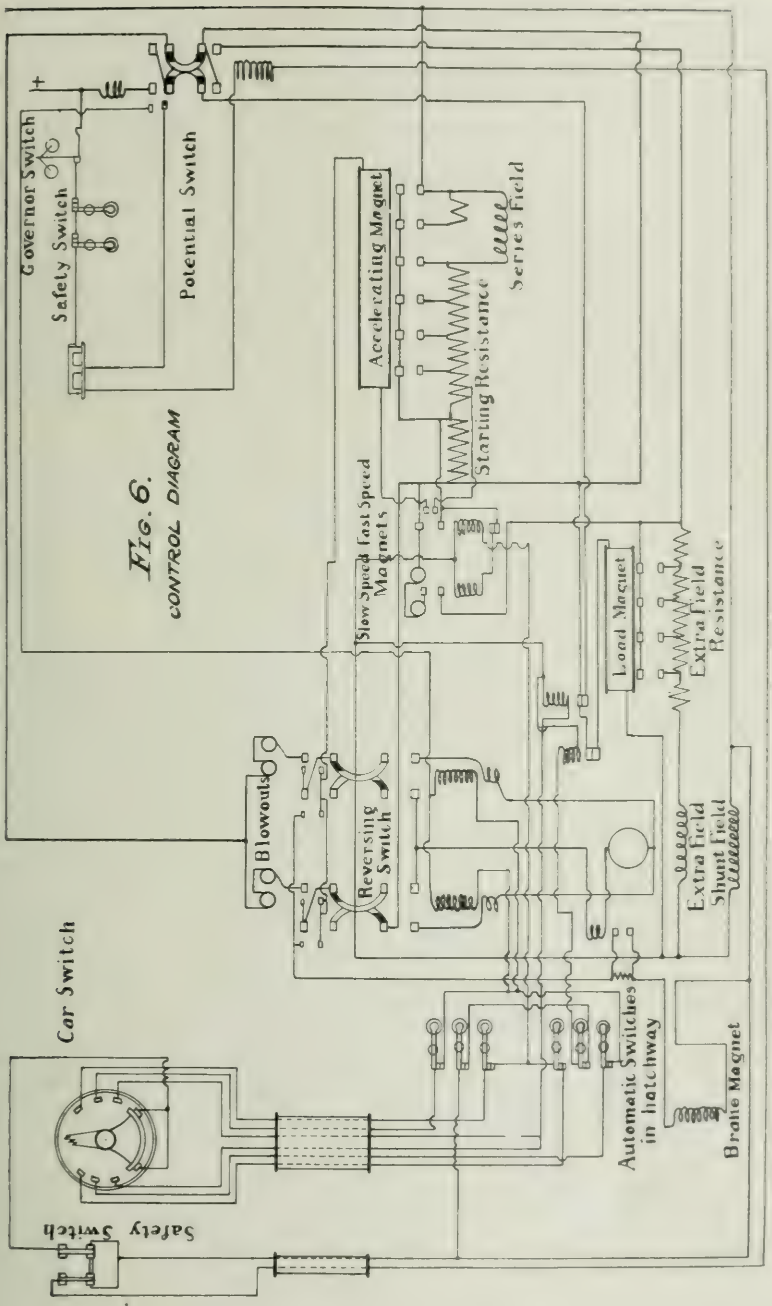


Fig. 6.
CONTROL DIAGRAM

hatchway, which closes the circuit of the energizing spool of the load magnet. This is connected to the terminals of the motor armature. It consequently becomes energized according to the potential of the motor armature at the moment when its circuit is made, and this potential, as explained, varies with the load. The load magnet will consequently close more or less of its armatures, in accordance with the potential of the motor, or the load on the car. With a heavy load down all the magnet armatures will be closed, and with a heavy load up none of the magnet armatures will be closed. The resistance in the circuit in parallel to the motor armature, will therefore be varied inversely as the load, so that the slow-down speed of the motor can be regulated to be the same for all loads, or the motor can even be given a slower speed for heavy loads down than for light loads. This load magnet provides means to make a safe automatic stop from high speeds in a short distance, consequently with small loss of time and power.

With these highly efficient machines, the cars can start from rest without the application of power, on removal of the brake. To prevent the brake from being released before the power of the motor is established, a magnet is introduced which controls the brake circuit. It closes only under the action of the armature current. Consequently the armature current must be established before the brake can be released.

A wiring diagram is shown in Fig. 7 with some variations from the above, in the arrangement of the slow-down magnets. This is used where it is deemed desirable to provide the operator with means of running at a great variety of speeds, from a very slow speed up to the full speed. The reversing switch and the accelerating magnet are the same as before. The installations for which this controller has been used are provided with shunt motors; no series field is consequently shown; also no extra field winding. The slow speed is made by variation of resistance in series with the armature, and in parallel to the armature, and by increasing the strength of the shunt field. For this four magnets are provided, which on their upper contacts control resistance in series, and on the lower contacts resistance in parallel to the motor armature. The spools energizing these magnets are under control of the operator in the car as well as under the control of the automatic stop motion for top and bottom landings. With the circuits of all the spools broken, the four upper contacts are opened, and the four lower contacts closed, giving the maximum resistance in series to the armature, and the minimum resistance in parallel to the armature, with very slow resultant speed of the machine.

By moving the car switch to right or left one after the other of the slow speed magnets close their upper contacts and open the lower contacts, decreasing resistance in series with the armature, and increasing resistance in parallel to the motor armature, establishing at the same time the magnetizing circuit of the accelerating magnet,

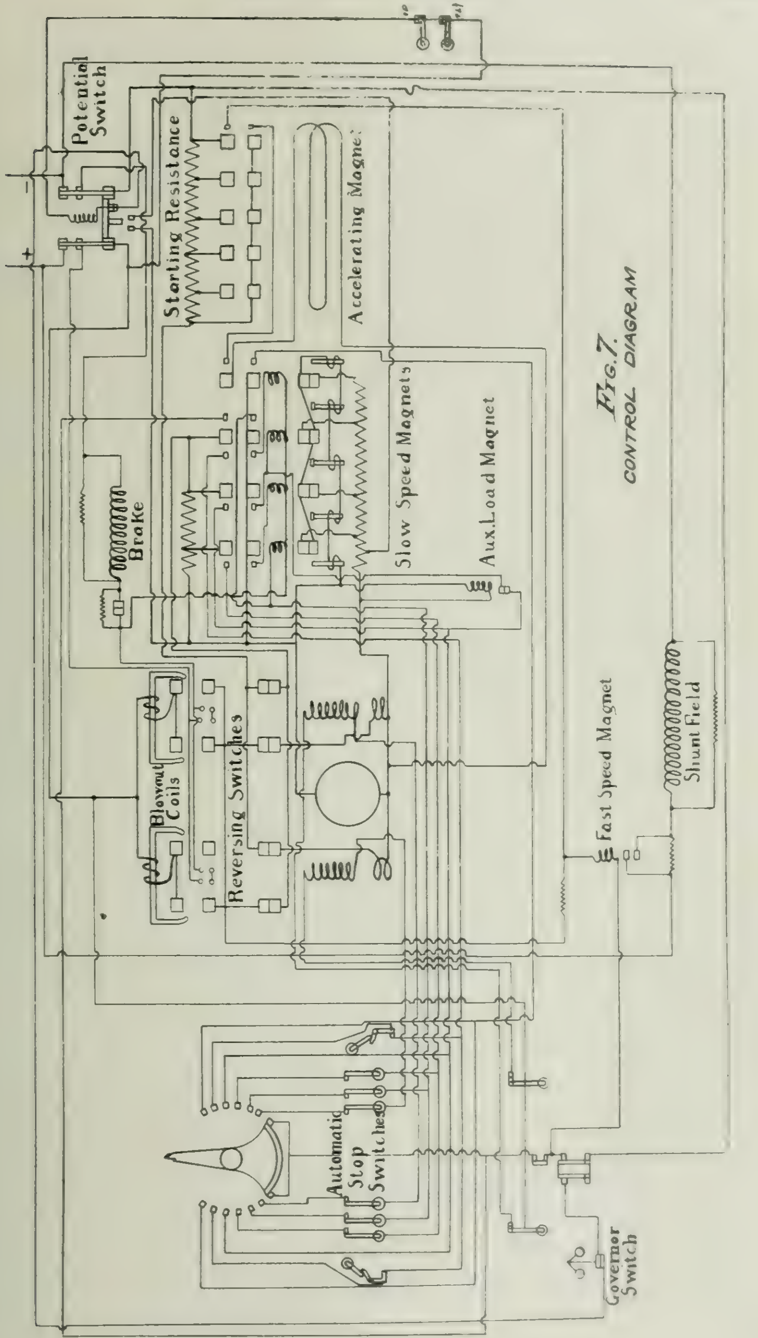


FIG. 7.
CONTROL DIAGRAM

which, as in the previous controller, automatically as the speed of the motor increases short-circuits all the starting resistance. The reverse takes place in slowing down, either under the action of the car switch or the automatic. If under the action of the automatic stop, whether with a heavy load going up, or empty car going down, the speed reduction should become too great, the small auxiliary load magnet connected to the motor armature, closing its contacts, re-energizes some of the low speed magnets, thereby reducing the resistance in series, and increasing the resistence in parallel to the motor armature, which automatically speeds up the motor again until the limit of travel is reached, where the reversing switch is opened and the brake is dropped, stopping the elevator.

To insure perfectly reliable operation, a number of electrically operated safety devices are installed, which act in case any of the standard parts of the operating device should fail. A potential switch on the controller, which is closed as long as the power is established, provides sure and quick independent means of breaking the main line current, dropping the brake, and giving a powerful dynamic brake action to the motor. It is called into action by limit switches in the hatchway, placed beyond the usual travel of the car. A safety switch in the car, which is connected to this potential switch circuit, enables the operator to stop the car at any time by means of this switch, if the car through any disarrangement of the circuits should not respond to the car switch.

A governor switch is provided to slow down or stop the car in case the speed from any cause whatsoever should exceed the maximum speed for which the machine is intended. An excess potential magnet is sometimes provided, either to slow down or to stop the car, in case of excess of speed, resulting in increase of potential on the motor armature. This is a magnet with normally closed contacts. Its magnetizing coil is connected to the armature terminals. If through excessive speed the potential of the armature is raised above the maximum contemplated, this magnet opens its contacts, thereby breaking a circuit, of either a slow speed magnet, or a circuit which stops the machine, whichever is deemed the most desirable.

The mechanical brake is constructed to give on each half a perfectly independent action. Failure of any part of the brake will consequently leave at least half the brake power available, which is sufficient for ordinary service even with an inexperienced operator, so that only in special cases will it be desirable to install an additional safety brake.

The automatic slow-down and stop switches are mounted in the hatchway, where they are operated directly by the car. They can consequently not get out of adjustment, but are bound to act always at the proper moment.

The elevators are provided with oil buffers under the counterbalance as well as under the cars. They are proportioned to take care of runaway cars, or in extreme cases, of cars getting beyond

control and running the maximum speed they can attain under the action of gravity. These buffers give protection against injury when all other safety devices have failed to act. After either car or counterbalance have landed on the buffers the tension of the driving rope is eased, and therefore the driving sheave even if the motor should keep on running, cannot break the rope by straining the car or counterbalance against the overhead beams.

The usual *Speed Governor* and *Emergency Lever*, operating a safety clutch device under the car is used, as on all other high class elevators.

A comparison of the economy of operation of the hydraulic and electric elevators has led to frequent discussion without coming to any definite conclusion, on account of the variation of power consumed by the electric elevator due to the design of the motor, its method of control, and the service to be performed.

Electric elevators consume power in proportion to the duty done, which gives a decided advantage over the hydraulic elevators where the same amount of water is used independent of the duty, and where (except in a few special cases) the same amount of pressure is also used. On the other hand, this is not a clear gain against the hydraulic, since the electric elevator consumes extra power for starting, and in some cases for stopping, and has a low efficiency at reduced speed. These radically different characteristics of the two types of elevators make a fair comparison difficult, but by considering broadly the general conditions, we can readily see which type must have the advantage.

A number of curves (Figs. 8, 9, and 10) taken on an actual machine by a recording ameter illustrates the importance of the different operations better than figures can do it. They show at a glance the wide variation in power consumption under different conditions of operation.

In a paper read by Mr. Thomas E. Brown before the American Society of Civil Engineers in 1904 data for different hydraulic elevators are given, which will be used here for a comparison. He finds that the vertical high pressure machine has the best economy of all types of hydraulic machines, and quotes the following figures:

Maximum load-L	2500 lbs.
Speed in feet per minute with maximum load	250 ft.
Speed in feet per minute with 1500 lbs. load	600 ft.
Rise of car	200 ft.
Weight of car	3400 lbs.
Unbalanced weight-U	1148 lbs.
Length of gravity stop-S	8 ft.
$L \div (L + U)$	0.685
Mechanical efficiency	0.832
Load efficiency	0.570
Hydraulic efficiency with full load	0.96
Final net efficiency	0.547

The electric 1:1 traction machine for the same load and 600 ft. maximum speed will have at least the same mechanical efficiency, since the armature and idler friction must be less than the multiplying sheaves, piston, pipes and valves. There is no loss for unbalanced weight, while the motor efficiency for full load is about 84%, which gives the electric machine when running full speed a final net efficiency of 70% against about 55% for the vertical high pressure hydraulic machine.

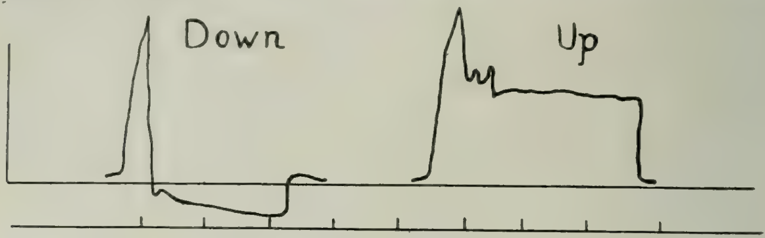


Fig. 8

These figures cover the full load running duty; that is, full load up and empty car down, for both types, the electric being half full load overcounterbalanced. Under these conditions the electric shows 15% better efficiency than the hydraulic.

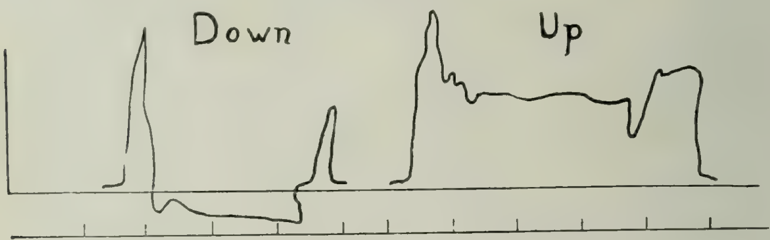


Fig. 9

This condition is represented on the straight part of the up curve on Figs. 8, and 9. The peak on Fig. 8 shows the extra power taken at starting, and the two peaks on Fig. 9 the power taken for starting and for the automatic stop by first going on slow speed. In Fig. 8 the stop is made from the car from full speed, so that no extra power is taken from the line, the dynamic brake power being supplied by the moving motor.

If the motor and controller were designed to keep the peak at starting, and the peak for the automatic stop, not to exceed 15% over the full load running power, we would have for the electric traction machine with full load up and no load down, making stops at all floors, the same power consumption as is required for the best hydraulic with all loads. This operation is shown on up curve Fig. 10,

where, with a stop at every floor, starting current only is recorded, the distance not being sufficient to bring the machine to running duty; but since the elevator for an average in a day's run lowers as many passengers as are raised, and does not stop at every floor, the power consumption will be an intermediate between the curves of Figs. 8, 9, and 10, so that even with a starting and stopping peak greatly in excess of the 15% considered, the all day power consumption for a well designed 1:1 electric traction machine must be considerably lower than that required for the same duty hydraulic machine. How great this gain will be, depends on the starting torque of the motor, the type of controller used, and the number of stops made.

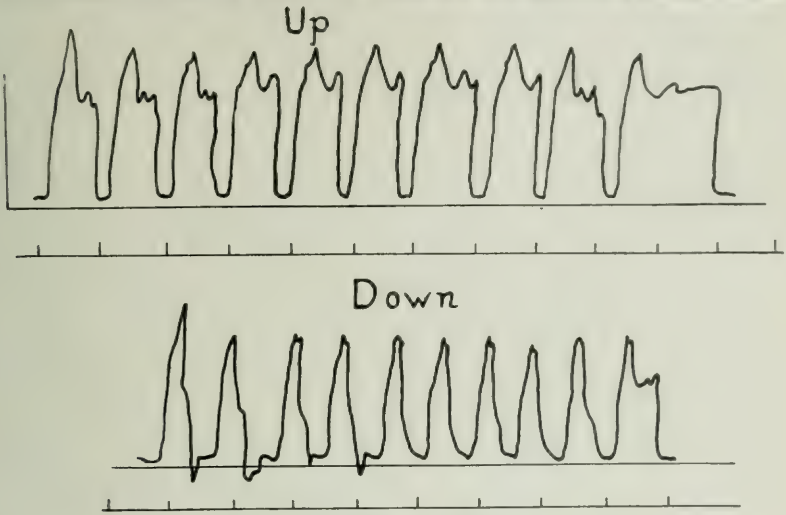


FIG. 10.

Regarding the efficiency of service, comparison between similar elevators confirms the theory that the electric traction machine gives a quicker start and stop, and does not have the great reduction of speed for heavy loads which we find in the hydraulic machine.

For the comparison as to the power consumption, we have above assumed that the peak for the power at starting should not exceed 15% over the full load running power. There is, however, nothing to prevent us from increasing the starting current to a greater amount, thereby increasing the rate of acceleration without increasing materially the power consumption. This can be readily carried to the limit which is compatible with the comfort of the passengers.

The ascending gravity stop in the high pressure hydraulic, where as the machines are generally installed no advantage can be taken of retarding the piston, depends on the unbalanced weight of the car, which has to overcome the momentum of the moving masses.

This is in the quoted case a distance of 8 feet with 1148 lbs., unbal-

anced weight. In the electric machine, since the driving sheave assists in arresting the descending mass, the gravity stop can be made in as short a distance as the comfort to the passengers allows.

The electric traction machine with its quick start and stop and small speed reduction with load will consequently give more rapid service with less expense than the hydraulic machine; and since it can be considered as safe as the hydraulic, we may confidently look forward to its general adoption in buildings requiring high speed service.

Discussion.

Mr. D. W. Roper, M.W.S.E., chairman. Elevators for high building have long been considered the cream of the elevator business, and as the architects, in their developments for building construction, add a few more stories, the elevator men in turn make such changes in their apparatus as will meet the requirements for those high buildings. I believe that the electric and hydraulic elevator people have had, for many years, the high building trade, and, as has been remarked in this paper, the hydraulic elevator was, for a time, in the lead. It is now hoped and contended by the electric elevator men that they have an elevator system which is the equal of the best that can be furnished by the hydraulic elevator people. That is possibly a point which the hydraulic elevator men will not admit without discussion and it is hoped to have that point brought out this evening.

Mr. Ernest F. Smith, M.W.S.E. I would ask what the average consumption of current is, in kilowatt hours per car mile, of the type of elevator described this evening.

Mr. H. Russel Smith: I think perhaps the best way to answer that question is to give the results of a test made on an elevator in actual service. During the six days' run, averaging practically 20 miles a day, the average current consumption was 2.67 kilowatt hours per car mile. Under tests made with fewer stops the current consumption fell below 2, kw. hr., but the results in taking the tests were not as valuable, from the standpoint of the user, as those taken of the week's run.

Mr. S. M. Bushnell, M.W.S.E.: I have been much interested in the paper this evening. I can remember very well when the electric elevator was first brought to my attention, and it is somewhat of a coincidence that the gentleman who read Mr. Ihlder's paper this evening is the one who first came into our office to talk electric elevators. At that time the central station company was a little in doubt as to whether the electric elevator was something they wished to connect to their system. The sudden starting and stopping, the sudden inrushing of the current required—also the variation in load—were things which at that time did not appeal to the central station manager, but as time has gone by it has been found that the elevator load on the central station is one of the best classes to be had; the variation in individual elevators is counterbalanced by other elevators working at the same time, so that the elevator load gives us nearly a straight

line on a central station load chart. The electric elevator might be regarded as the last link in the chain of complete power service which may be supplied either from the large electric plant or from the central station. No one supposed, twenty years ago, that the distribution of power would be a large percentage of the central station business, but as time has gone by we have found that one field after another has come into line, until the electric elevator has become the only thing on which there was any question.

I have paid some attention to the matter of efficiencies of elevators, and have collected data from different installations, and found that the average kilowatt consumption of the hydraulic elevator operated by electric motor was about double that of direct electric machines. This conclusion is based both on the average cost of small elevators on a central station, and also on tests made on larger elevator installations such as the Chicago Savings Bank building; the store of Carson, Pirie, Scott & Co., etc.

I was much interested in Mr. Smith's statement regarding the kilowatt consumption per car mile. We made a test on a traction machine here in the city, lasting two days, and during that time the kilowatt consumption averaged 2.52 kw. hr. per car mile. This elevator was carefully watched during that time and exact records taken of the amount of current consumed. The results shown by the monthly readings of meters have led me to think that the average consumption on traction electric elevators in ordinary operation, runs somewhere between 2.52 and 3 kw. hr. per car mile.

Mr. John W. Mabbs: I am particularly interested, as many of you know, in the subject of elevators for high buildings, and I have listened with interest to the reading of Mr. Ihlder's paper on the electric traction elevator. It seems to me that in the machine described none of the dangers of the electric drum machine are eliminated, and what is worse, this elevator does not keep the safety features of the drum machine, but operates on a much more *unsafe* basis. In the first place this machine does not do away with the dangers of counterweights, which are acknowledged by all to be one of the greatest, (if not *the greatest*) sources of serious accident. It seems to me if the traction of the hoisting ropes on the driving pulley is sufficient to raise a heavily loaded car, it would be sufficient to pull the car into the overhead work in one direction, or pull the counterweights out of their guides in the other direction, in case of failure of the controller, and resulting in the possibility of serious accident. Further, it is an utter impossibility to put mechanical limit stops on this machine, and I think all will agree with me that the car is not the proper place for installing limit stops. Secondly, this machine leaves out the safer method of transmission of power, viz., by worm gearing, and installs instead practically a shaft free to rotate in well lubricated journals, and in case of failure of current, there is nothing to prevent the precipitation of the car and its load either into the basement or against the roof timbers, according to the condition of load, except an

electro-mechanical brake; it seems a fatality that operating mechanical devices are apt to fail when most needed. Another dangerous feature of this machine is that all the power required to lift the load is applied by friction to the lifting cables, which cannot help but seriously shorten the life of said cables, and endanger the lives of the passengers carried, to the same extent.

I wish to present to you this evening (Fig. 11) an electric elevator which was designed particularly for high buildings, high speed and great safety. This elevator has been pronounced by able casualty insurance men to be the safest electric elevator in existence. You will see by referring to Fig. 11 that the machine forms the counterweight of the car and is all the counterweight there is; it is a self-supporting and self-propelled counterweight. Its construction is more clearly shown in Fig. 12. It is worm geared and climbs up and down two vertical columns by means of four pinions which engage four racks mounted on the two vertical columns. These pinions are mounted on two horizontal shafts, on each of which shafts, is a worm gear, which is actuated by a worm mounted on the vertical armature shaft of the motor. As the motor ascends the car descends and vice-versa. The machine is geared two to one, so for every foot the machine travels, the car travels two feet, consequently the machine hatchway extends but half the height of the building.

In addition to a very simple and reliable system of automatic stops at both ends of the travel of the machine, it is provided with absolute mechanical oil buffers at both ends of the travel (shown in Fig. 11), which are sufficient to take care of the machine if the controller and all the automatic stops should fail, making it an utter impossibility to either pull the car into the overhead work or drop it into the basement, or to put a strain on the cables greater than the load in the car. All through the design of this machine, the factor of safety used is extra great.

The speed of these elevators, in operation, ranges from 540 ft. to 600 ft. per minute. A much higher speed can be safely given if desired.

The operation of these elevators is ideal, it being possible to reverse the cars at full speed without a perceptible pause and without a particle of shock or jar. These cars will start and stop quicker and with less disagreeable sensation than any hydraulic elevator.

One of these elevators has been in constant operation in the Chicago Board of Trade Bldg. for the past five and one-half years, and to date the car has made over 27,000 car miles; the original hoisting cables are still in service and in good condition. The reliability of this machine is shown by its missing only one day's run in over four years. After three years uninterrupted service by this first machine, the Directors of the Chicago Board of Trade threw out the other electric elevators previously in use and installed four more of these machines (Fig. 13), which have now been in operation over two years, and in that time one machine has missed but one day. These

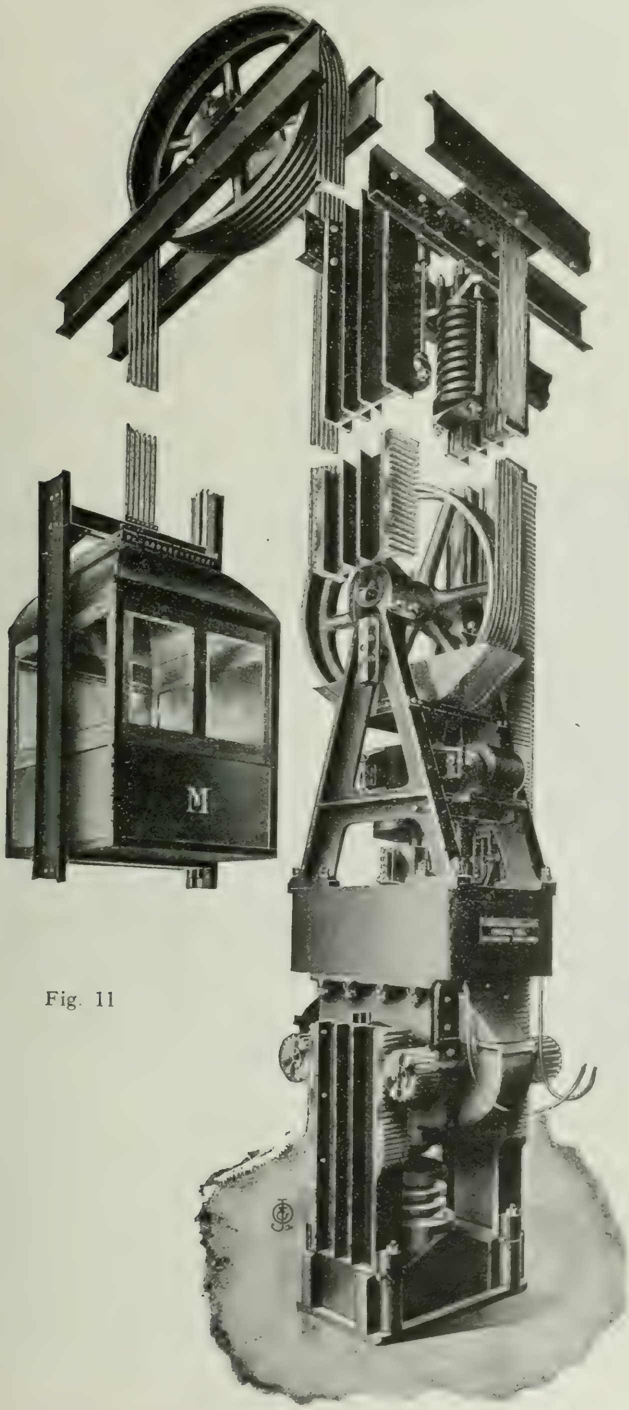


Fig. 11

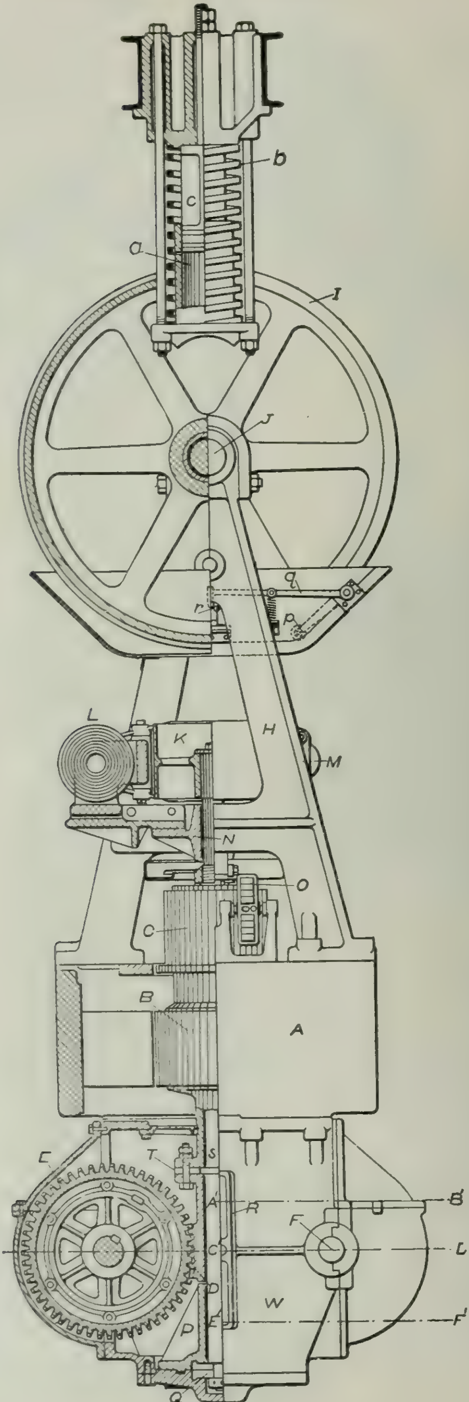


Fig. 12.

four machines in a single year showed a saving over the electrical machines they replaced of $2,000 in repairs, $1,440 in current, and $1,000 in labor, and increased the elevator service 46%. The repair bill of these machines, for repairs of every description, including machines, controllers, cables, lights, signals, cars, gates, etc., has averaged less than $85.00 per elevator per year. The four elevators shown in Fig. 13 made 22,874 car miles last year, or 469,939 trips, being an average of 376 trips per elevator per day. The elevator service in the Chicago Board of Trade Bldg. is pronounced by one of the ablest and best known elevator and electrical men in this country, to be "the severest in the United States," yet under these conditions and operating at the high speed they do, the average current consumption for these elevators to date is 3.54 k.w. per car mile. Fig. 14 shows a bank of the controllers which are full magnet control built by J. L. Shureman & Co., Chicago.

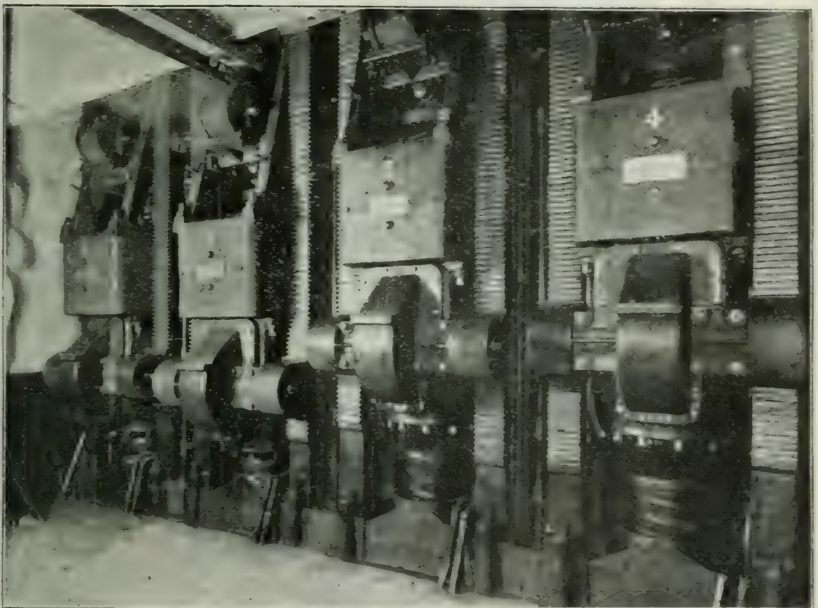


Fig. 13.

Mr. Geo. M. Mayer, M.W.S.E.: How does the cost of installing this electric elevator compare with that of other types?

Mr. Mabbs: It is not a cheaper elevator to install, although I do not think others ask any less to install theirs, except when compelled to by competition. The advantage of this machine is that it is durable, reliable and safe.

I would ask Mr. Smith what happens to his car if the current is suddenly shut off and the brakes fail to act?

Mr. Smith: About the same thing as would happen to yours, only the car itself lands on buffers, and would undoubtedly come to a standstill in a better way than if allowed to dangle on ropes.

Mr. Mabbs: This machine is worm gear driven and it would be a difficult matter to overhaul it.

Mr. Huston: I would ask Mr. Mabbs how he avoids the trouble of noise usually found with gearing apparatus?

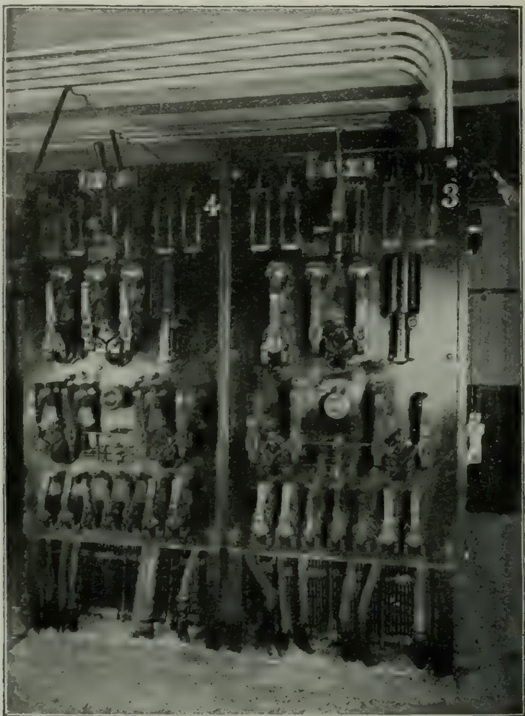


Fig. 14.

Mr. Mabbs: With this machine, when properly installed, one can stand with his back to it and not know whether the machine is moving or not. The gearing runs much more quietly than the brushes on a commutator.

Mr. Mayer: I would ask in regard to the design of the worm gearing in connection with Mr. Mabbs' car.

Mr. Mabbs: The worm gearing is so designed that when the car is standing still it will not start, but if the car should start it will overhaul *slowly*—that is, with a *maximum load.* With an ordinary load it will not overhaul. The momentum does not increase as the car ascends or descends, as the may be.

Mr. Mayer: I would ask Mr. Smith what is the greatest elevation to which they have elevators running.

Mr. Smith: 1000 feet. The elevator which Mr. Mabbs has described might, as he said, be extended to the moon, provided he could get his guides there, but he would also have to get his machinery construction half way there, and there might be some difficulty in that.

Mr. A. Scheible, M.W.S.E.: Does anyone know what type of elevator that is being placed in the new Singer building in New York; and in the Metropolitan tower, which is still higher?

Mr. John Blake: The question of efficiency has come up, and my understanding is that the efficiency of the hydraulic elevator was given as 50 per cent, and that of the electric elevator as 70 per cent. In the case of the Standard Plunger elevator, I believe the efficiency is considered to be 90 per cent. That type of elevator is not represented here tonight. I would ask how far back that efficiency of 50 per cent goes?

Mr. Smith: The efficiency of the hydraulic elevator is particularly hard to get at and I am not fully qualified to answer that question. The efficiency of an hydraulic elevator goes beyond the actual mechanism for operating the car. As stated in the paper, Mr. Brown selected the highest and most efficient type of hydraulic elevator, which is known as the inverted plunger type. The only packing in the machine is around the lower end of the plunger. The efficiency of operation of an hydraulic plant goes back to the pumps; an hydraulic plant being operated either with steam pumps or pumps operated by electric motors. Mr. Brown figured that it takes double the current to do the same work with hydraulic elevators and electrically driven pumps, that it would with direct connected electric elevator apparatus, of the drum type, and that is very easy to see, as the electric elevator consumes power approximately in proportion to the work done. All electric elevators are over-balanced to about one-half of the live load and that would cut the figure in two. If we put in a large plant of elevators—six, eight or ten—and operate them on regular schedule, and put in for their operation a high duty pump, using steam, with a large degree of economy, then it is susceptible of demonstration that such a plant will operate with less consumption of power than any electric elevator devised, but for small plants or those doing irregular service, the operation of an hydraulic plant is not economical. One or two elevators requiring a pumping plant will cost considerably more for installation than electric elevators doing exactly the same work. For that reason the electric elevator has made a great advance during the last fifteen years, and has displaced the hydraulic elevator where it is possible to get current, or where some other question does not make the selection of an hydraulic elevator preferable to the electric elevator.

Mr. Scheible: Several of the speakers tonight have referred to the kilowatts per car mile required, without specifying the size of the car or average number of passengers. Are we to understand that the

variations in the size of the car or average number of passengers constitute so small a percentage as to be negligible?

Mr. Mabbs: The cars of the Mabbs elevator are considerably larger than most of the cars in the city (36 square feet) and they carry a great many more passengers than any traction elevators I know of. Three of the traction elevators in this city carry 300 passengers in an hour during their busy period, whereas three of the Mabbs cars often carry that number in 10 to 15 minutes.

Mr. Junkersfeld: I would ask what was the controlling reason for using the electric elevator in the 47-story Singer building in New York.

Mr. Smith: The selection of a type of elevator for the Singer building was determined after a very thorough investigation. I think it is easily proven that, as far as safety is concerned, the traction type of elevator, as described, has as many elements of safety as the hydraulic type, and is just as safe. The Singer building, as I understand it, was so designed as to make the installation of hydraulic machinery undesirable; it also has a much higher rise than ordinary elevators have been built for and a combination of these reasons led to the selection of the traction type of elevator for the purpose.

Mr. F. G. Cox: I think the chief factor which decided the selection of the traction type of elevator for the Singer Building was the small amount of space required for this installation. The peculiar design of this building made an hydraulic installation out of the question, owing to lack of room in the basement.

In deciding upon a type of machine for overhead installation the drum type would have caused trouble on account of the length of drum required for the high rise and consequently excessive width of hatchway necessary. The traction type seems to be just the machine required on account of its compactness, simplicity, small number of parts and efficiency in operation, and it seems that this type is the only available machine which would suit the conditions of that building and of all high office buildings where space is of considerable importance.

Mr. Wm. B. Jackson, M.W.S.E.: It would be interesting to know how much return of current there actually would be in such an elevator as described.

Mr. Smith: It depends somewhat on the form of meter the power company puts in; also on the preponderance of load in either direction. In the Marshall Field building they have a very peculiar service. They have various banks of elevators to carry people up, and other banks to carry them down. They are electric elevators, and it may be that the elevator in going up empty would pump current back into the lines. Whether the meter which has been put in by the power company has been fixed to take care of that, I do not know. I know it is true to some extent that the meters are reversed.

Mr. Roper: The lighting company does not have meters on the individual elevator but on the bank of elevators.

Mr. Bushnell: Mr. Pearson, the Electrician for the Marshall Field

Company, has made very careful tests, but they are not yet in shape for publication.

Mr. Scheible: I heard Mr. Cravath remark about some sort of a differential scheme of electric elevators which was in use for some time in certain Chicago buildings and which was uncommonly efficient. Can he tell us why this was abandoned, or at least not more widely adopted?

Mr. Cravath: Mr. Smith can probably answer that question better than I can.

Mr. Smith: The principle of the apparatus is two motors, one mounted above the other, with double traction apparatus. With these motors it is possible to get much greater variations of speed than with the type we have been talking about. It was difficult to find any rope that would stand the strain of running at high speed over the pulleys of comparatively small diameter, and this type of apparatus has practically been given up.

Mr. Mayer: Both Mr. Smith and Mr. Mabbs have emphasized the point regarding safety. I have heard that there are cars equipped with a device, so that the car, in falling, would be acting like a piston. Can anyone here say anything along that line?

Mr. Roper: I believe some elevators of that type have been installed.

Mr. Mabbs: The name of that device is the Ellithorpe air cushion. It is constructed by making the lower part of the elevator shaft airtight and of sufficient length below the bottom landing to insure stopping the car by compressing the air before it reaches the bottom, and undoubtedly it is the safest device one can put under a car in case of failure of ropes or anything of that kind.

Mr. T. W. Heermans: I expect to see the electric elevator take the place of many of the hydraulic elevators now used. I first went into the hydraulic elevator business over twenty years ago. There are many such in this city which have been running over twenty years and are doing good service, but unless they are provided with an economical pumping plant they are much more expensive to operate than the electric type.

Mr. Mayer: Why is it that the safety devices provided in the cars sometimes fail to act?

Mr. Smith: That is just what the elevator men are trying to find out. Often the fault is due to the men caring for the elevator, who do not keep the device in readiness for operation.

I think the hydraulic elevator will be used for some time to come, when we consider that at present there is several million dollars worth of property in process of construction, where only these elevators are considered so far. For certain purposes they seem to fill the bill better than others.

TESTS OF CAST IRON AND REINFORCED CONCRETE CULVERT PIPE

BY ARTHUR N. TALBOT, M.W.S.E.

Presented April 15, 1908.

This paper will give the results of tests made on cast iron pipes and reinforced concrete pipes in the Laboratory of Applied Mechanics of the University of Illinois. The pipes used in the tests were furnished by the five railroad companies which co-operated with the University of Illinois Engineering Experiment Station in the work, and acknowledgment is made to the Atchison, Topeka & Santa Fe Ry. System, Chicago, Burlington & Quincy R. R. Co., Chicago, Milwaukee & St. Paul Ry. Co., Chicago, Rock Island & Pacific Ry. Co., and Illinois Central R. R. Co., for this and other favors extended. Messrs. D. A. Abrams and W. R. Robinson of the Engineering Experiment Station gave valuable assistance in the investigation. The tests were made between November, 1906, and January, 1908. The work was an outgrowth of certain thesis investigations upon the strength of concrete rings and reinforced concrete rings, the data of a part of which are included in this paper. Further details of the tests will be given in a bulletin of the Engineering Experiment Station soon to be issued, but it is felt that the members of the Society may be interested in having the results presented in condensed form without further delay.

The tests were intended to throw light upon the strength of pipes placed in railroad embankments, but the results may be useful in discussions of sewers and other similar forms of construction. The main tests were made with a specially prepared testing apparatus which included a box of strong and stiff construction, and the pipes were embedded in sand and the load applied through a saddle which rested on a sand cushion. Auxiliary tests were made to connect the investigation with the action of the pipes in other methods of testing. Thus, rings which were cut from the spigot ends of the cast-iron pipe were tested under concentrated load, and small test pieces were also cut out and tested. Short rings of concrete and reinforced concrete were tested, both under concentrated load and under distributed load. In different ways these auxiliary tests served to check up the phenomena of the tests of the pipes and to assist in interpreting the action of the testing apparatus, the distribution of the load, and the resisting strength of the structures themselves.

MECHANICS OF PIPES AND RINGS SUBJECT TO EXTERNAL PRESSURE.

Bending Moment and Conditions of Loading.—The stresses developed in rings subject to external earth pressure, as in sewers and railroad culvert pipes, are of course dependent upon the bending moments developed, and, as the exact load coming upon the ring and its distribution over the surface are difficult to determine, the bend-

ing moment is in general quite uncertain. The amount of the load and its distribution, and therefore the bending moments on different parts of the ring, depend upon a number of conditions, among them the nature of the earth used in the filling, the method of bedding the pipe, the way of tamping the earth at the sides, the amount of the lateral restraint or pressure of the earth horizontally, the method of filling and packing the earth above, the condition of moisture in the earth, etc. Evidently in such earth as quick-sand, the conditions may approach those of external hydrostatic pressure, and on the other hand, in deep sewer trenches, the earth filling may act so that its weight is carried against the sides of the trench. In discussing the stresses in rings, it may be well first to find the bending moment for certain assumed conditions of loading, then to make tests under various conditions of loading, and finally to compare these results with a view of determining the probable range of bending moments under the actual conditions of construction. The assumed loadings may include:

(1) a concentrated load at the crown of the ring,

(2) a vertical load distributed uinformly over the horizontal section,

(3) a distributed vertical load together with a horizontal load distributed vertically over the sides of the ring,

(4) an oblique loading.

In these calculations, since much uncertainty is involved, the difference in the intensity of the load at the crown and at the extremities of the horizontal diameter, due to the different depths of earth, need not be considered. In general the pressures and distribution on the lower half of the ring will be considered to be the same as on the upper half. It is apparent that in a ring of considerable thickness in comparison with its diameter there is a different distribution of stresses from that found in thin rings, but for the rings under consideration the simplicity of analysis for thin rings will outweigh the small loss in accuracy. As refinements are not essential and approximations are permissible, the equations will be based upon a thin ring of homogeneous material having a constant modulus of elasticity and it will also be assumed that the changes from a circular form will have little effect upon the dimensions of the ring. As the derivation of the formulas is somewhat long, only the final equations will be given and the reader is referred to the bulletin of the Engineering Experiment Station already mentioned for the complete analysis.

Concentrated Load.—For a load concentrated as shown in Fig. 1 (a), the quadrant shown in Fig. 1 (b) will be in equilibrium under the load 1/2 Q at B, a thrust 1/2 Q at A, a moment 0.091Wd at A, and a moment 0.159Wd at B. At B

$M = 0.159Wd$. . . . . (1)

For a point C at an angle Φ above the horizontal diameter, (Fig. 1 (c)), the equation for the bending moment is

$$M = Qd\ (0.159 - 1/4 \cos \Phi) \qquad (2)$$

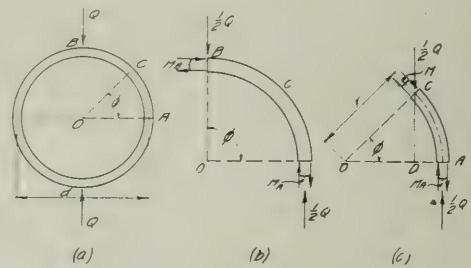


Fig. 1. Ring under Concentrated Load.

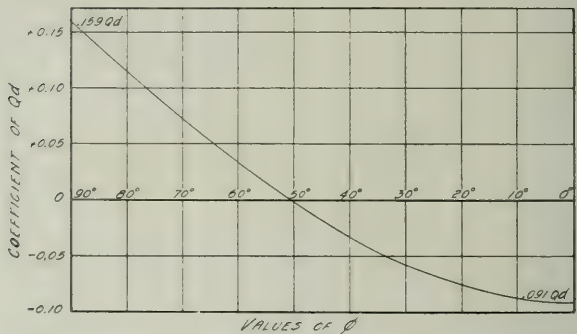


Fig. 2. Variation in Bending Moment for Concentrated Load.

Fig. 2 shows the changes in bending moment between the haunches and the crown. The point of zero bending moment is $\Phi = 50° 30'$. At this point the sign of the bending moment changes from negative to positive. The expression for the deflection of the pipe under concentrated load or for the change in vertical diameter is $0.0186 \dfrac{Qd^3}{EI}$ and for the change in horizontal diameter is $0.0171 \dfrac{Qd^3}{EI}$.

Distributed Vertical Load.—For a vertical load distributed uniformly over the horizontal section as shown in Fig. 3 (a), the quadrant shown in Fig. 3 (b) will be in equilibrium under the load, a thrust at A, a moment at A and a moment at B. Calling the load on the ring W and the mean diameter of the ring d, the moments at A and B, which are equal, are given by the expression

$M=1/16\ Wd$, ...(3)

For a point C at an angle Φ above the horizontal diameter, (Fig. 3 (c)), the equation for the bending moment is

$M=1/16\ Wd\ (1-2\cos^2\Phi)$,................................(4)

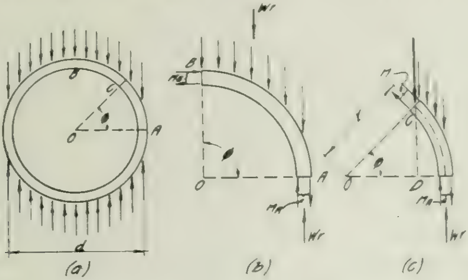


Fig. 3. Ring under Distributed Vertical Load.

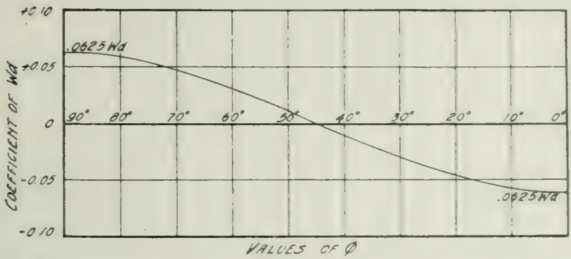


Fig. 4. Variation in Bending Moment for Distributed Load.

In Fig. 4 is shown the change in bending moment between the haunches and the crown. The point of zero bending moment is $\Phi=45°$. At this point the sign of the bending moment changes from negative to positive. The expression for the deflection of the pipe, or for the change in vertical diameter, is $1/96\ \dfrac{Wd^3}{EI}$, and the change in horizontal diameter is the same.

Distributed Vertical and Horizontal Load.—If now we consider that the vertical load is uniformly distributed over the horizontal section of the pipe as before and that there is also a horizontal pressure uniformly distributed vertically against the pipe, the loading will be as represented in Fig. 5 (a). If the ratio of the horizontal pressure to the vertical pressure is denoted by q, the moments at A and B will be given by the equation

$M=1/16\ (1-q)\ Wd$,......................................(5)

For a point C at an angle Φ above the horizontal diameter (Fig. 5(b)), the equation for the bending moment is

$M=1/16\ Wd\ (1+q-2\cos^2\Phi-2q\sin^2\Phi)$....................(6)

The bending moment becomes zero at $\Phi=45°$, as in the other case.

If the intensity of the horizontal pressure is the same as that of

the vertical pressure, $q=1$, and M becomes zero at all points. This corresponds to uniform external pressure, and equal compression is produced in all parts of the ring.

Oblique Load.—In the case of both the concentrated load and the distributed load it is seen that the bending moments at A and B are large and that the moment decreases to zero amount at some point between A and B. If we were sure that this loading obtained, no provision against bending need be made at the points of zero bending moment and but little for points close on either side. However, it must be borne in mind that if there is a change from the specified loading, the conditions of the bending moment are likewise changed. If, for example, the method of filling over the pipe should be such as to make the pressure come obliquely as shown in Fig. 6 (a), the maximum bending moment would be at the 45° points and the minimum moments at the ends of horizontal and vertical diameters. Similarly, if in a sewer trench, a slip of earth from the side caused the pressure to come against the sewer as shown in Fig. 6 (b), the distribution and amount of the bending moment would be materially different from that of the vertical loading usually assumed. In the case of a large sewer in a shallow trench, during the time of filling, especially with the concrete still green, the direction of pressures indicated in Fig. 6 (c) would give bending moments quite unlike those before described. It will be necessary to make separate analyses for such cases. While an accurate measurement of the bending moments in such cases is impossible, yet in any case it is feasible to judge of the amount and location of the bending moments within reasonable limits and to provide strength in the section of the sewer to take the consequent stresses.

Resisting Moment and Stresses.—For a ring whose thickness is small in comparison with the diameter the difference in the length of the inner fiber and outer fiber is small and the expression for the resisting moment given for ordinary straight beams may be applied with a close degree of approximation. In the following formulas the length of the ring (width of beam) will be considered unity. Call t the thickness of the ring.

For the rectangular section of the ring the resisting moment will then be $1/6\ ft^2$ where f is the unit-stress at the remotest fibre. In those sections in which there is no thrust, the maximum stress (stress at the remotest fiber) may be found by equating the expression for the resisting moment and the expression for bending moment and substituting the numerical values at the section considered. If a thrust exists at the given section, this thrust may be considered to be uniformly distributed over the section and the stress will be equal to the sum or difference of the resisting moment stress and the thrust stress.

For a concentrated load at the crown (Fig. 1) the stress at B, since there is here no thrust, may be determined from the formula

$1/6\ ft^2 = 0.159\ Qd$, ... (7)

At A the same form of expression may be used for the resisting moment, but this must be combined with the stress due to the vertical thrust. Considering this to be uniformly distributed, the stress in the remotest fibers will be

$$f = \frac{Q}{t} \mp \frac{0.091\ Qd}{1/6\, t^2} \quad \dots\dots (8)$$

The — sign will be used for the outer fiber and the + sign for the inner fiber.

At any point C Fig. 1 (c) the stress at the remotest fiber may be shown to be

$$f = 1/2 \frac{Q \cos \Phi}{t} \pm \frac{M}{1/6\, t^2} \quad \dots\dots (9)$$

For a uniformly distributed horizontal load the stress at the crown B will be

$$f = 1/16 \frac{Wd}{1/6\, t^2} \quad \dots\dots (10)$$

and at A

$$f = 1/2 \frac{W}{t} \pm 3/8 \frac{Wd}{t^2} \quad \dots\dots (11)$$

and at any point C Fig. 3 (c),

$$f = \frac{Wr \cos^2 \Phi}{t} \pm \frac{M}{1/6\, t^2} \quad \dots\dots (12)$$

For a distributed vertical and horizontal load (Fig. 5) there will be a thrust both at A and B. The stresses at the crown B will then be given by the following equation:

$$f = ½ \frac{qW}{t} \pm \frac{M_B}{1/6\, t^2} \quad \dots\dots (13)$$

At A the extremity of the horizontal diameter

$$f = ½ \frac{W}{t} \pm \frac{M_A}{1/6\, t^2} \quad \dots\dots (14)$$

At any point C (Fig. 5 (b)), the expression for the stresses may be written

$$f = 1/2 \frac{W \cos^2 \Phi}{t} - 1/2 \frac{qW \sin^2 \Phi}{t} \pm \frac{M}{1/6\, t^2} \quad \dots\dots (15)$$

These formulas are directly applicable to homogeneous elastic rings in which the modulus of elasticity of the material remains constant. These conditions are not strictly true for rings made of cast iron or of concrete or reinforced concrete. However, they may be applied without any great error to cast-iron rings and plain concrete rings at the breaking loads, if the modulus of rupture of the materials obtained under the same condition of thickness and loading be substituted for the maximum tensile stress f. It should be noted that the stress on the tension side will generally control.

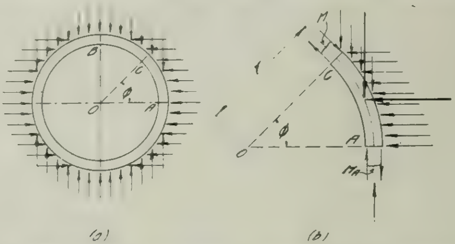


Fig. 5. Ring under Distributed Vertical and Horizontal Load.

For a ring made of reinforced concrete the conditions differ somewhat from the foregoing. For ordinary cases it will not be far from the truth to equate the bending moment determined as above and the resisting moment of the reinforced concrete section. As the amount of reinforcement is usually much lower than that in which the circular beam would fail by compression in the concrete, we may, without material error, take for the resisting moment of the reinforced concrete section the value 0.87 Aft, where t is the distance from the compresion face to the center of the steel reinforcement, A is the area of the cross-section of the reinforcement for a unit of width of ring, and f is the tensile unit-stress in the steel due to the bending moment. To equate the bending moment determined as above to this resisting moment, is not exactly correct, since among other reasons the neutral axis does not come at the center of the thickness of the ring (which is the point about which the bending moments were taken) and since the elastic curve is not the same as in a ring of homogeneous material. At sections where thrust occurs, as at A, Fig. 1 (c) and 3 (c), the tension in the steel determined as above will be reduced by the resisting compressive stresses there set up. The amount of the tension in the steel at the point A may be calculated by the formula

$$f' = f - \frac{1/2\, nT}{t\,(1+np)} \quad \ldots\ldots (16)$$

which is applicable for both concentrated and distributed loads. In this formula f is the tensile stress in the steel due to the bending moment, p is the ratio of the area of reinforcement for a unit width of beam to the distance between the center of the steel and the compres-

sion face of the concrete, T is the intensity of thrust or pressure against the face of the section, and n is the ratio of the moduli of elasticity of steel and concrete, which for purposes of this calculation may be taken as 15. At the extremity of the horizontal diameter the thrust is W. At the crown it is zero for vertical loading, and for both concentrated and distributed load the greatest tensile stress is found at this section.

Conditions of Bedding and Loading Found in Practice.—The foregoing discussion assumes certain definite conditions of loading. These are useful in establishing definite formulas which may be used as a basis for calculations. It is not to be expected that these conditions represent accurately the condition of bedding and loading to be found in practice. It is then desirable that the nature and extent of possible or probable variations from these assumed conditions be discussed and the effects of such a divergence considered. The following are suggestions of variations; the engineer will easily extend the discussion by numerous examples taken from his own experience.

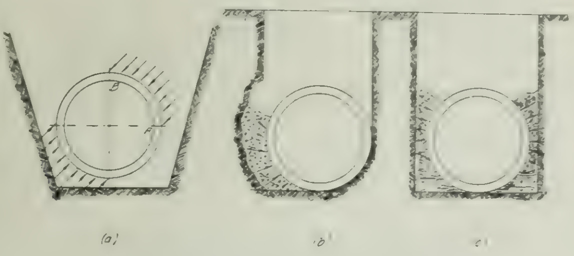


Fig. 6. Varieties of Loading.

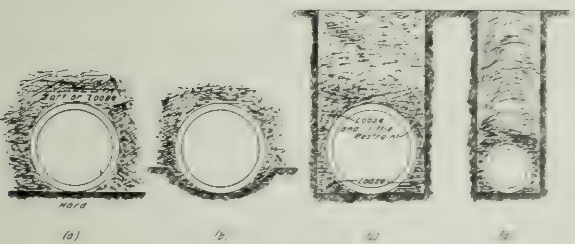


Fig. 7. Conditions of Loading.

If the layer of earth immediately under the pipe is hard or uneven, or if the bedding of the pipe at either side is soft material or not well tamped as indicated in Fig. 7 (a), the main bearing of the pipe may be along an element at the bottom and the result is in effect concentrated loading. This condition may be aggravated in the case of a pipe with a stiff hub or bell where settlement may bring an unusual proportion of the bearing at the bell and the distribution of the pressure be far from the assumed condition.

In case the pipe is bedded in loose material, the effect of settlement will be to compress the earth immdiately under the bottom of the pipe more completely than will be the effect at one side, as indicated in Fig. 7 (b), with the result that the pressure will not be uniformly distributed horizontally. Similarly, in a sewer trench, if loose material is left at the sides and the material at the extremity of the horizontal diameter is loose and offers little restraint, as indicated in Fig. 7 (c), the pressure on the earth will not be distributed horizontally and the amount of bending moment will be materially different from that where careful bedding and tamping give an even distribution of bearing pressure over the bottom of the sewer.

In the case of a small sewer in a deep trench, the load upon the sewer may be materially less than the weight of the earth above, in the case as shown in Fig. 7 (d), where the earth forms a hard compact mass and is held by pressure and friction against the sides of the trench.

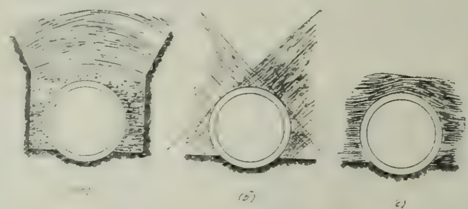


Fig. 8. Conditions of Loading.

In case a culvert pipe is laid in an ordinary embankment by cutting down the sides slopingly as shown in Fig. 8 (a), it is evident that the load which comes upon the pipe will be materially less than the weight of the earth immediately above it. If a culvert pipe replaces a trestle and the filling is allowed to run down the slope as shown in Fig. 8 (b), the direction and amount of the pressure against the pipe will differ considerably from that which obtains in a trench or in the case of a level filling shown in Fig. 8 (c).. It is possible in the latter case that the smaller amount of settlement of the earth directly over the culvert pipe, due to the greater depth of earth on the adjacent sections, may allow a greater proportion of the load to rest upon the culvert pipe than would ordinarily be assumed.

Attention should be called to the fact that the distribution of the pressure by means of earth under and over a ring assumes that the earth is compressed in somewhat the same way as when other material of construction is given compression. Unless the earth has elasticity, the distribution of pressure can not occur. To secure the uniform distribution assumed, the ring itself must give enough to allow for the movement of the earth which takes place under pressure. This is especially true with reference to the presence and utilization of lateral restraint, and a ring which does not give laterally, as for example a plain concrete ring, will not develop lateral

pressure in the adjoining earth under ordinary conditions of moisture and filling to any great extent. As the conditions of earth and moisture produce mobility and approach hydrostatic conditions, the necessity for this elasticity and movement do not exist, but here the lateral pressure approaches the vertical pressure in amount and the bending moments become relatively smaller.

The discussion is sufficiently extended to indicate the importance of care in bedding culvert pipe and sewers and in filling over them, and to indicate the great difference in the amount of bending moment developed with different conditions of bedding and filling. Where there is any question of needed strength, it will be money well expended to use care and precaution in bedding the pipe and in filling around and over it. I am convinced that a little extra expense will add considerable stability, life, strength, and safety to such structures, far out of proportion to the added cost. It is possible that under careful conditions of laying lighter structures may be used with a saving in the cost of construction.

MATERIALS, TEST PIECES, AND METHOD OF TESTING.

Cast-Iron Pipe and Rings.—Nine cast-iron culvert pipes were tested, four being of 36-in. inside diameter and five being of 48-in. inside diameter. Four pipes were furnished by the Atchison, Topeka and Santa Fe Ry., two each by the Chicago, Milwaukee & St. Paul Ry. and the Chicago, Rock Island & Pacific Ry., and one by the Illinois Central R. R. The thickness of the pipe varied, both light-weight and medium-weight being used. One pipe was 6 ft. 8 in. long, and the others ranged from 8 ft. 0 in. to 8 ft. 5 in. over all after the rings for use in the auxiliary tests had been cut from them. Test pieces, 2 inches wide and about 24 inches long, were afterward cut from these rings and tested in cross-breaking. The quality of the cast-iron in the pipes was very good. Data on the pipes and rings are given in Table 2.

Reinforced Concrete Culvert Pipe.—Five reinforced concrete culvert pipe were furnished by the Chicago, Burlington and Quincy R. R. They were made at Montgomery, Ill. Owl brand portland cement was used. The gravel came from a pit at Montgomery. A mechanical analysis of the gravel is given in Table 1.

In two pipes the reinforcement was ¼-in. corrugated bars, placed as shown in Fig. 9, and ½-in. corrugated bars were used in one pipe. One pipe was reinforced with "Clinton Wire Mesh," No. 3 wire being used, and the fifth pipe was reinforced with fence wire laid in the center of gravity of the concrete. The steel which was placed lengthwise of the pipe is not considered in figuring the reinforcement. To allow the steel to be made circular in shape, the pipes were made with the vertical diameter four inches longer than the horizontal diameter. This brought the reinforcement at the points where tension would be present in the loaded pipe. Four of these pipes had a nominal inside horizontal diameter of 48 in. and the

other a nominal inside horizontal diameter of 36 in. This horizontal diameter will be used in referring to the pipe, the vertical diameter being 4 in. longer. The barrel of the pipe was 4 in. thick. The bell extended 4 in. beyond the barrel and had the same thickness, its inside diameter being 1 in. greater than the outside diameter of the barrel.

The forms were of wood lined with galvanized iron and were placed vertically with the bell up. These forms were removed when the concrete was from two to four days old and the pipes were, stored in the open air until after shipment to the University, where they were stored in the testing laboratory. Pipe No. 982 was made in cold weather and was heated by steam coils to aid the curing of the concrete. Examination indicated that the quality of the concrete was somewhat injured thereby. All the pipe had very good surface and, when broken up, appearances indicated a very good quality of concrete.

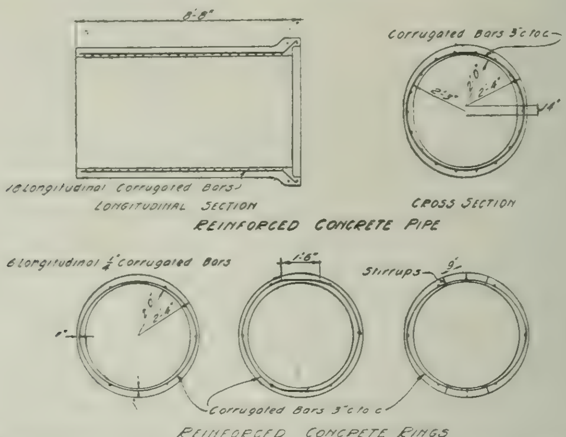
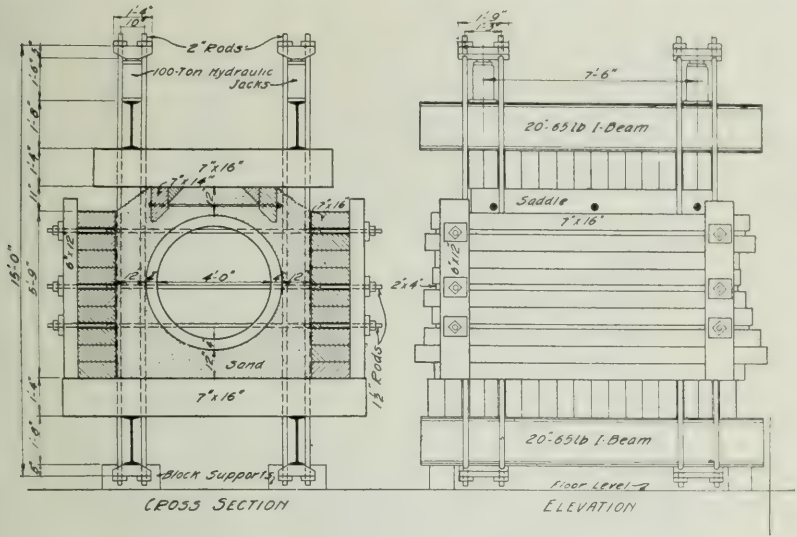


Fig. 9. Distribution of Reinforcement in the Reinforced Concrete Pipes and Rings.

Concrete and Reinforced Concrete Rings.—The concrete and reinforced concrete rings were made in the laboratory at the University. The sand came from near the Wabash River at Attica, Indiana. It was of good quality and contained from 28% to 30% voids, as determined by standard methods. The stone was Kankakee limestone which showed about 50 voids. Universal Portland Cement, furnished by the manufacturers, was used. The concrete, which was made rather wet, was thoroughly mixed by hand in the usual manner, the mixture being 1:2:4 in all cases. The steel used in the reinforced rings was ¼-in. mild steel corrugated bars.

The rings were all circular in section, 4 ft. in inside diameter, and 2 ft. long, the reinforcement being placed as shown in Fig. 9. The reinforced rings, of which there were 16, were 4 in. thick, while the

8 plain concrete rings were made 6 in. thick. In most of the rings the steel was shaped somewhat like an ellipse in order to bring the reinforcement near the tension side at the quarter points. In No. 934, 971, and 972 the bars were flattened for a distance of 18 inches at both top and bottom of the ring, and in No. 976 and 977 three



. Fig. 10. Hydraulic Jack Testing Machine.

crimped pieces of steel were placed at top and bottom across the ring. These were spaced 9 in. apart and served the same purpose as stirrups in a beam.

Testing Machine for Distributed Load.—The machine used for testing the culvert pipe is shown in Fig. 10. The photograph given in Fig. 11 will aid in giving an idea of the apparatus used. The floor of the machine rested on two I-beams. A layer of sand was spread over this floor. On this layer of sand was placed the pipe to be tested. The sides of the box were built up with bridge timbers and held firmly laterally by heavy rods. Sand was put around and over the pipe. The sand was leveled off at the top and the saddle built. Two I-beams, similar to those below the pipe, were placed on the saddle and at the four corners were placed hydraulic jacks with a capacity of 100 tons each. The plungers bore against heavy cast-iron blocks which were connected to blocks under the lower I-beams by means of 16 heavy wrought-iron rods. The jacks were operated by pumps placed on top of the saddle. In this way a fairly even loading of the pipe was obtained.

The loads were read from a dial attached to each pump. Such calibrating of these dials as has been done indicates that there is usually

an initial error and that the per cent error is much smaller on high loads than on small ones.

Method of Testing.—Every effort was made to have the pipe level in the sand. As the sides of the box were built up, the sand was frequently soaked down with water from a hose to insure firm bearing around and over the pipe. The operation of bedding the pipe and building up the box for each test was carefully done, and the time

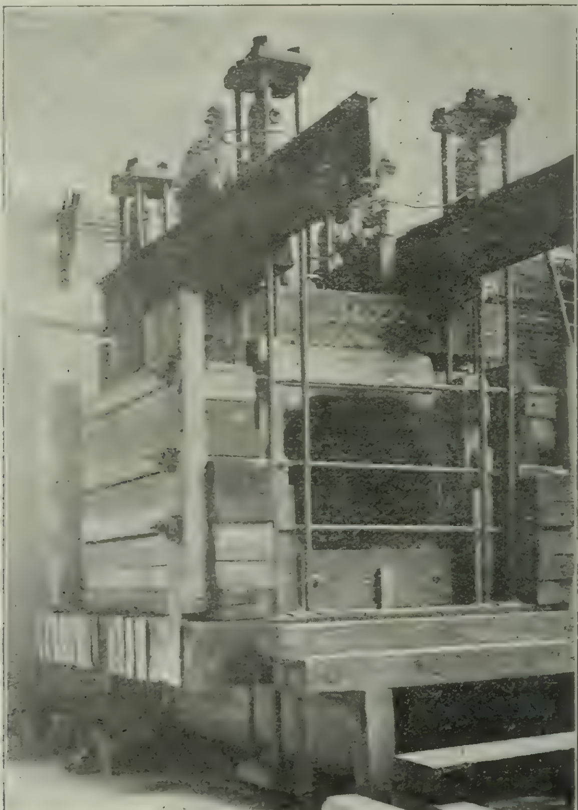


Fig. 11. View of Hydraulic Jack Testing Machine.

and labor involved in this and in making the test were considerable. Points were marked on the inside of the pipe to indicate the extremities of vertical and horizontal diameters at sections 1 ft. inside each end of the pipe. Initial readings of the diameters were taken. Then the load was put on in increments of 16,000 lb. and held while readings of the diameters were taken. As each crack appeared its size and location were carefully noted. This was continued until the pipe had reached complete failure.

The rings which were tested with distributed load were set up in a

similar way except that the box and saddle were only long enough to accomodate a 2-ft. length of pipe. The box was set up on the bed of the 600,000-lb. Riehle testing machine and the load was applied by running the head down on the saddle. Readings of the horizontal and vertical diameters were taken at the center of the ring, the load being applied in increments of 1,000 lb.

All the testing under concentrated load was done in the 600,000 lb machine. A layer of plaster of paris about ¼ in. thick was spread on a strip of building paper lying on the bed of the machine. The ring was put in place so that the bottom element rested in the plaster of paris. A similar layer of plaster was put on the top of the ring and a cast-iron bar 3 in. wide by 2 in. thick by 2 ft. long was carefully centered in the plaster over the top element. A second bar of the same dimensions was afterward placed on top of this to give greater stiffness. The head of the machine was then run down and the load applied through a hemispherical bearing block.

EXPERIMENTAL DATA WITH CAST IRON PIPE AND RINGS

Data of Tests.—Table 2 gives dimensions of the cast iron culvert pipe and rings and the name of the railroad company which furnished the pipe. The suffix A denotes the ring cut from the spigot end and the suffix B the ring next to it. In all cases the remainder of the pipe as tested contained the bell of the original pipe. (given in Table 4 under the heading of Pipes). Table 3 gives the results

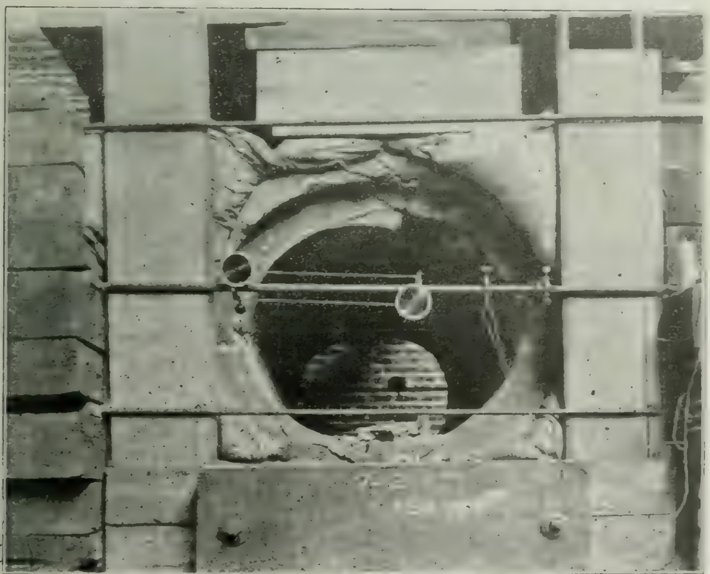


Fig. 12*a*. View of Reinforced Concrete Pipe After Test.

of the concentrated-load tests and Table 4 the results of the distributed-load tests.

In Fig. 13 to 17 are given diagrams showing the amount of the vertical and horizontal deflections of the pipe, at both the spigot end and the bell end, which were produced under the load per lineal foot of pipe or ring indicated by the vertical scale. The full line shows the change in horizontal diameter and the dotted lines the change in vertical diameter. These diagrams will be discussed for the two methods of loading.

Concentrated-Load Tests.—The cast-iron rings which were tested under a concentrated load gave phenomena similar to what would be expected from the analysis of the bending moments and resisting moments. As is shown on the diagram in Fig. 13 the amount of deflection is nearly proportional to the applied load. The value of the modulus of elasticity given in Table 3, calculated from the expression for deflection, for loads and deflections near the breaking load

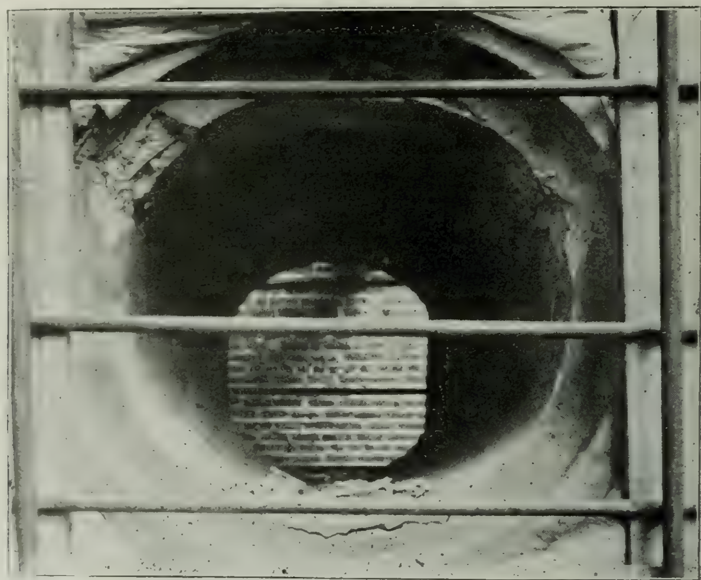


Fig. 12*b*. View of Reinforced Concrete Pipe After Test.

(10,200,000 lb. per sq. in.), is somewhat smaller than the average value of the modulus of elasticity determined from the tests of rectangular specimens cut from the pipe. This is not unexpected for a material as variable in its elastic properties as cast iron and with such a difference in form as the ring and the straight rectangular beam. It seems that the value of the modulus of elasticity determined from the deflections of the rings may best be used in the investigation of the rings and pipe.

At the maximum load sustained, the rings failed at either the top or the bottom, and the rupture extended over the entire length of the pipe in every case. This accords with the theoretical determination already made, it having been found that the bending moment at the top or bottom is about 16/9 that at the extremities of the horizontal diameter. After rupture occurred the machine was in some cases run on down to give greater deflections, but the load then sustained was much less than the breaking load and the rings finally broke again, this time at the ends of the horizontal diameter.

It will be seen that the average value of the modulus of rupture calculated by equation (7) and given in Table 3, is 27,000 lb. per sq. in. This is 25% less than the value of the modulus of rupture determined by loading at the center the rectangular test specimens taken from the rings. The difference which exists in the distribution of the stresses by these two methods of testing and the differences in strength of the materials in the two directions will partly

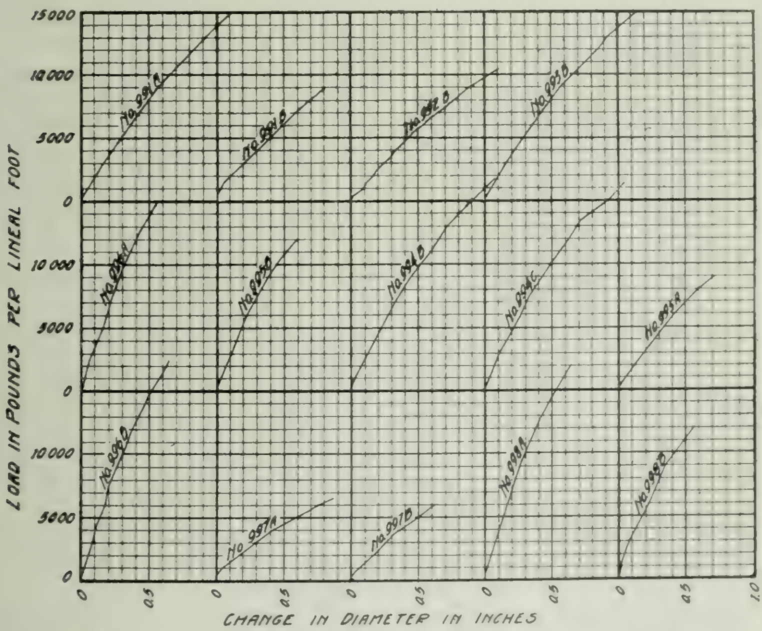


Fig. 13. Load-deflection Diagrams for Cast-Iron Rings. Concentrated Load

account for this difference. It seems probable that the results given in Table 3 are more nearly representative of the conditions in the rings and pipe, and in the calculations for the pipes and rings under distributed load the value obtained in the concentrated tests of the corresponding ring has been used.

Phenomena of the Distributed Load Tests.—In the distributed

load tests the pipe or ring was bedded in sand, the load was applied through a saddle resting on sand, and the sides of the test box were restrained, as already described. It is not probable that such a method of loading will give a uniform distribution of the load either longitudinally or transversely. It is evident from a study of results that the distribution of the load is uncertain and that the amount of the lateral restraint is also uncertain. While for the purposes of cal-

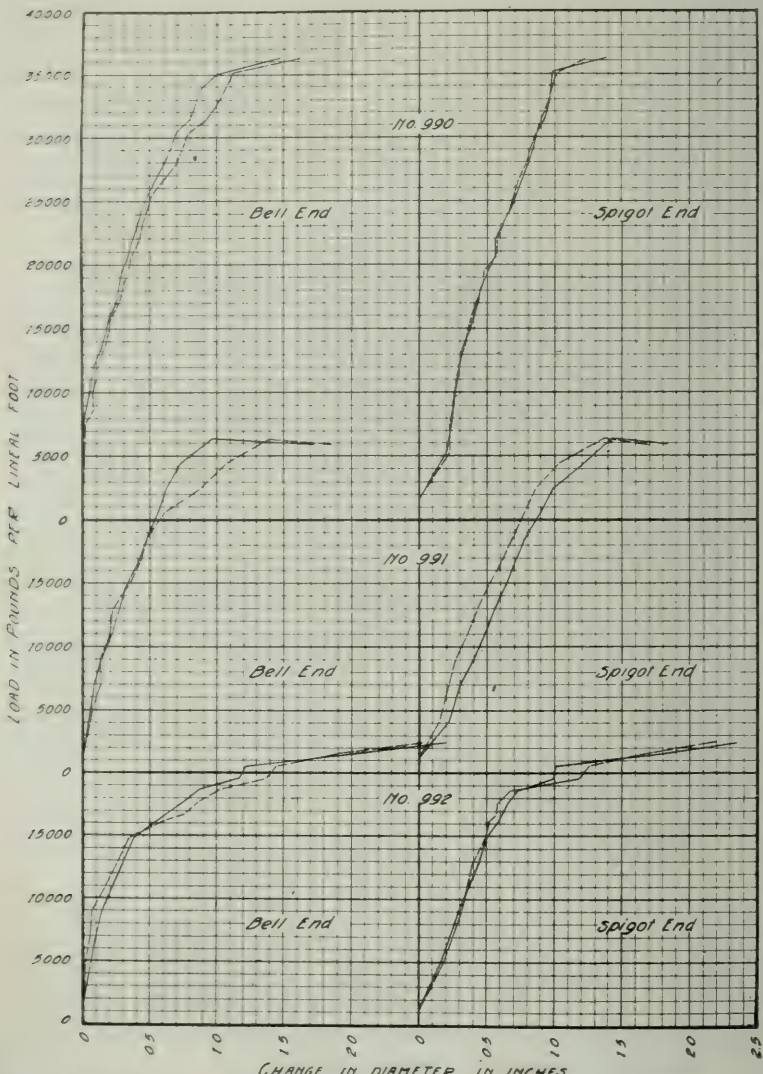


Fig. 14. Load-deflection Diagrams for 48-in. Cast-Iron Pipes. Distributed Load.

culation and discussion the distribution of the pressure may be assumed to be uniform over a horizontal section, it is plain that this does not express at all accurately the manner in which the load was distributed. However, a uniform distribution of the load may be used as a basis of comparison in the discussion of the results. A study of the load deflection diagrams given in Fig. 14, 15 and 16

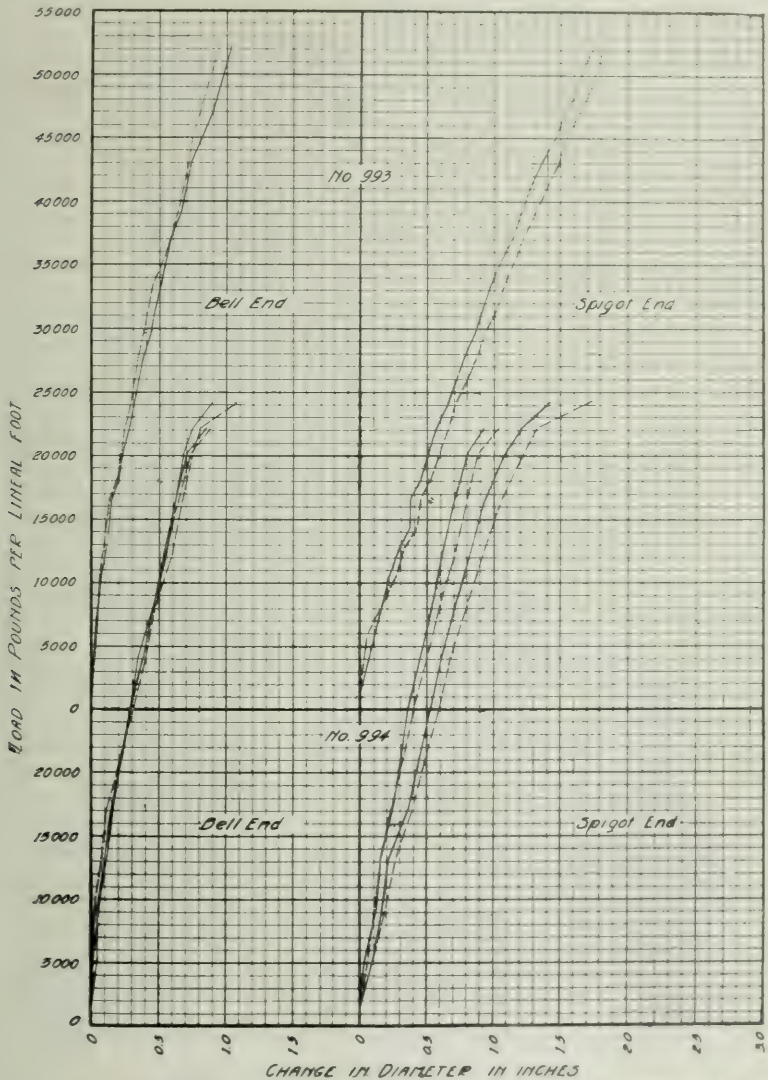


Fig. 15. Load-deflection Diagrams for 48-in. Cast-Iron Pipes. Distributed Load.

will show that the deflection at the spigot end generally began at once and increased nearly proportionally to the amount of the applied load, as is indicated by the approximation to a straight line. This is in accord with the analysis and with the form of the equation for deflections. At the bell end the deflections lagged behind and generally formed a curved diagram. It is evident that the great stiff-

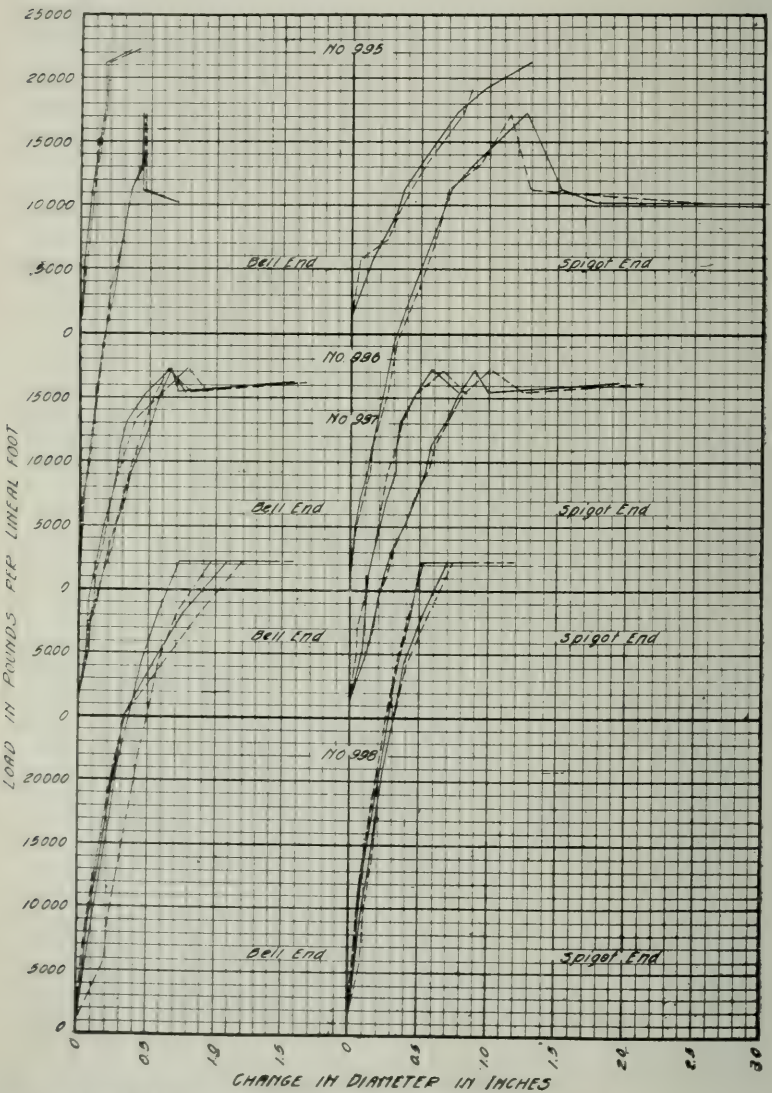


Fig. 16. Load-deflection Diagrams for 36-in. Cast-Iron Pipes. Distributed Load.

ness of the bell is the cause of this and that after the barrel of the pipe becomes distorted the effect is transmitted to the bell in varying proportions. At a load varying from 75% to 100% of the maximum a crack appeared in the top or bottom of the pipe except in No. 996 where it appeared at one side. Usually with an increase of load this extended toward the other end, and finally the pipe broke throughout the full length at or near the maximum load. This generally occurred at the top or bottom of the pipe. The further operation of the testing apparatus gave increased deflections, sometimes without a material reduction in the load and sometimes at a much lower load, until the pipe broke at some other point in the section.

The following notes of Pipe No. 992 and 994 give the typical phenomena of the tests.

No. 992. Diameter 48 in. Length 8 ft. 3 in. over all. Light-weight pipe, 6,900 lb. for 12 ft. net length. Small bell. Average thickness 1.3 in. Loaded 2 in. off center. At a load of 16,300 lb. per lin. ft. cracks formed at the top and bottom and extended through the bell 8 in. into the barrel. At 17,700 lb. the bottom crack extended from end to end, and at 18,700 lb. the top crack extended likewise. At 21,600 lb. both sides cracked from end to end. The load dropped off, and finally rose again, reaching 22,600 lb. per lin. ft. Test discontinued.

No. 994. Diameter 48 in. Length 8 ft. net. Heavy-weight pipe, 8,900 lb. for 12 ft. net length. Average thickness 1.58 in. This pipe was cut into two pieces and the end of one was loosely inserted in the bell at the middle of the testing box. The piece containing the bell is denoted the bell section, and the other the spigot section. The center of the loading apparatus was over the bell. The first crack appeared in the bell at the top and extended 2 ft. into the barrel at a load of 47,200 lb. per lin. ft. At the maximum load of 49,300 lb. per lin. ft. this crack extended the full length of the bell section. No crack appeared in the spigot section. Test discontinued.

The effect of lateral restraint is illustrated in the results of a preliminary test on Pipe No. 990. In this test the hydraulic jack machine was not used, but I-beams were used to transfer the load from the 600,000-lb. testing machine to the saddle, since the box was too large to be placed on the bed of the machine. The distance of the saddle from the testing machine was such that only one-fifth of the load on the machine was applied to the saddle. The load was run up to 16,200 lb. per lin. ft. on the pipe. At this point an I-beam commenced to buckle and the load was taken off. At this load the change in the vertical diameter was 0.37 in. The load having been taken off, the rods holding the sides of the box were loosened and kept loose and pressure again applied. This time, at a load of 15,500 lb. per lin. ft., the average change in the vertical diameter was 1.05 in. with no sign of failure. When the load was removed there was a set of 0.65 in. at the spigot end. Four hours later this set was reduced to 0.30 in. The deflections in the two tests are shown in Fig. 17. This pipe was finally tested to destruction in the hydraulic jack machine, the first crack appearing at a load of 26,400 lb. per lin. ft. and the pipe finally carrying 37,500 lb. per lin. ft. as has already been described.

Comparison and Discussion.—Table 4 gives data of the distributed-load tests of the cast-iron pipe and rings. The loads are given in pounds per foot of length of ring or pipe. The first crack for which the load is given appeared at the bell end in four pipes and at the spigot end in three. In No. 993 the crack ran from end to end and in No. 994 in which the pipe was cut and the spigot end placed in the bell end at the middle of the test box the first crack was at the bell. The breaking load was the maximum load and generally the indicated load of the testing apparatus fell off at once though in some cases the maximum load held until the deflections had been increased somewhat. M′ is the bending moment based on a uniform distribution of the breaking load over the horizontal section of the pipe and without any allowance for lateral pressure or restraint, as calculated by equation (3). Mo is the resisting moment of a rectangular section of the pipe, calculated with the value of the modulus

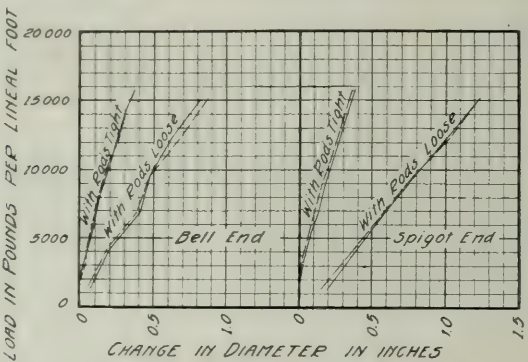


Fig. 17. Load-deflection Diagrams of Pipe. No. 990 tested with and without Lateral Restraint.

of rupture f determined from the concentrated load tests of the rings cut from the pipe, except that for No. 990, from which no ring was cut, the average modulus of rupture determined from other pipe was used. In the expression for the resisting moment b is the length of pipe or ring and t is the average thickness. The last column gives the ratio of the resisting moment to the bending moment thus calculated. If Mo properly measures the resisting moment and if the load is uniformly distributed over the horizontal section in both the longitudinal and transverse direction this ratio should be unity. If there is lateral pressure of the sand similarly distributed over the vertical section the value of the ratio should be less than unity and would represent the 1—q of equation (5). That is to say, if the ratio is 0.75, the lateral pressure would, by this method of reasoning, be 25% of the vertical load. This treatment does not consider the effect of the greater strength and stiffness of the bell nor the effect of the stiffness of the bell upon the stresses in the barrel next to the bell. It is

seen that there is a considerable variation in the value of the ratio. The higher values may be due to an uneven distribution of the load either longitudinally or transversely. In cases where the break occurred at one end or the other the lack of distribution seems evident. It is possible that in these cases the pipes were not so well bedded or that the sand was not so well packed about them. The lower values of the ratio indicate considerable lateral pressure. Evidently there is a great variation in the condition of loading and the distribution of the pressures and it is possible that uneven resisting stresses of the pipe may account partly for this variation. This question will be discussed further on.

EXPERIMENTAL DATA WITH CONCRETE AND REINFORCED CONCRETE PIPE AND RINGS

Data of Tests.—Table 5 gives manner of loading of the plain and reinforced concrete rings and pipes and the loads carried. Table 6 gives the results of the concentrated load tests and Table 7 the results of the distributed load tests. These will be discussed for the two methods of loading under different heads.

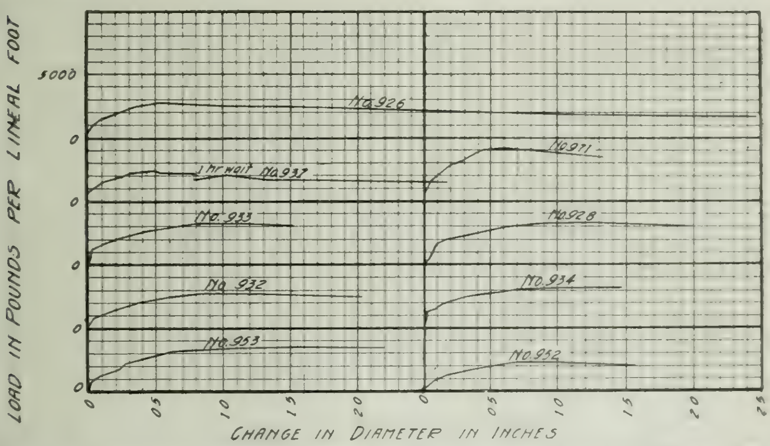


Fig. 18. Load-deflection Diagrams of Reinforced Concrete Rings. Concentrated Load.

In Fig. 18 to 21 are given diagrams of the amount of the vertical and horizontal deflections of the pipe and rings which were produced by the load per lin. ft. of length of pipe indicated by the vertical scale. A single full line shows the change in the vertical diameter. Where two lines are given, the full line shows the change in the horizontal diameter, and the dotted line the change in the vertical diameter. These diagrams will be discussed for the two methods of loading.

Concentrated-Load Tests.—The method used in testing the cast-iron rings and pipe was used for the tests on concrete and reinforced

concrete rings. As the plain concrete rings broke before there was an appreciable deflection no measurement of deflections was made. The modulus of rupture calculated from equation (7) is given in Table 6. All failures occurred in either the top or bottom section of the cylinder as is to be expected from the relative value of the bending moment at these points and that at the extremities of the horizontal diameter. The breaks were sudden and the load which could be carried after this break was very much less than the load at the time of the formation of the cracks.

The reinforced rings deflected considerably before final failure. At a load of 1,000 to 2,150 lb. per lin. ft., fine cracks appeared on the tension face, generally at the top or bottom much as they appear in tests of reinforced concrete beams. With the application of higher loads, numerous fine cracks appeared on the tension faces at the top, bottom, and sides. Two forms of critical failure were apparent; one a tension failure of the reinforcing bar at the top or bottom of the ring (stretching beyond the yield point of the metal), and the other a failure of the concrete by the stripping and shearing of the concrete from the tension face. The latter form of failure may correspond to the diagonal tension failure in beams. Sometimes the concrete was split off along the reinforcing bars and these bars were straightened from their original circular form. The following notes are typical of the tests:

No. 932. Fine cracks at top, bottom and sides at 1,500 lb. per lin. ft. At the maximum load of 3,000 lb. per lin. ft. the deflection was 0.85 in. Later the concrete began to strip off.

No. 934. A fine crack appeared at the top at 1,300 lb. per lin. ft., at the bottom at 1,550 lb. per lin. ft., and at the sides at 2,050 lb. per lin. ft. At 3,050 lb. per lin. ft. the deflection was 0.73 in. and at the maximum load, 3,150 lb. per lin. ft., it was 1.05 in. and the cracks at the top and bottom soon opened up 0.25 in., showing tension failure.

No. 952. A fine crack appeared at the bottom at 1,000 lb. per lin. ft., at the sides at 1,250 lb. per lin. ft., and at the top at 1,450 lb. per lin. ft. At a load of 2,250 lb. per lin. ft. the deflection was 0.97 in. At the maximum load, 2,350 lb. per lin. ft., the concrete split off and the rods broke through at the top.

No. 971. Fine cracks appeared at the top and bottom at 1,500 lb. per lin. ft. and at the sides at 1,750 lb. per lin. ft. At the maximum load, 4,120 lb. per lin. ft., the deflection was 0.6 in. Failed by tension in the steel at both top and bottom.

In Table 6 the bending moments at the maximum loads are given. In part of them, failure came by splitting of the concrete along the reinforcing bars. In some cases this was caused by imperfect fabrication, the bars being left too close to the interior face of the ring. The deflection curves have much the same characteristics. The maximum load gave a deflection of 0.5 to 0.8 in.

Distributed Load Tests of Concrete Rings.—The plain concrete rings which were tested under a distributed load, bedded and covered with sand and restrained at the sides as already described, cracked at the bottom, top, and sides at an early load. With the continued applica-

tion of the testing apparatus the load dropped off at first until at a somewhat greater deflection sufficient side restraint had been developed when the load again increased and continued to rise until a considerable change had been made in the vertical and horizontal

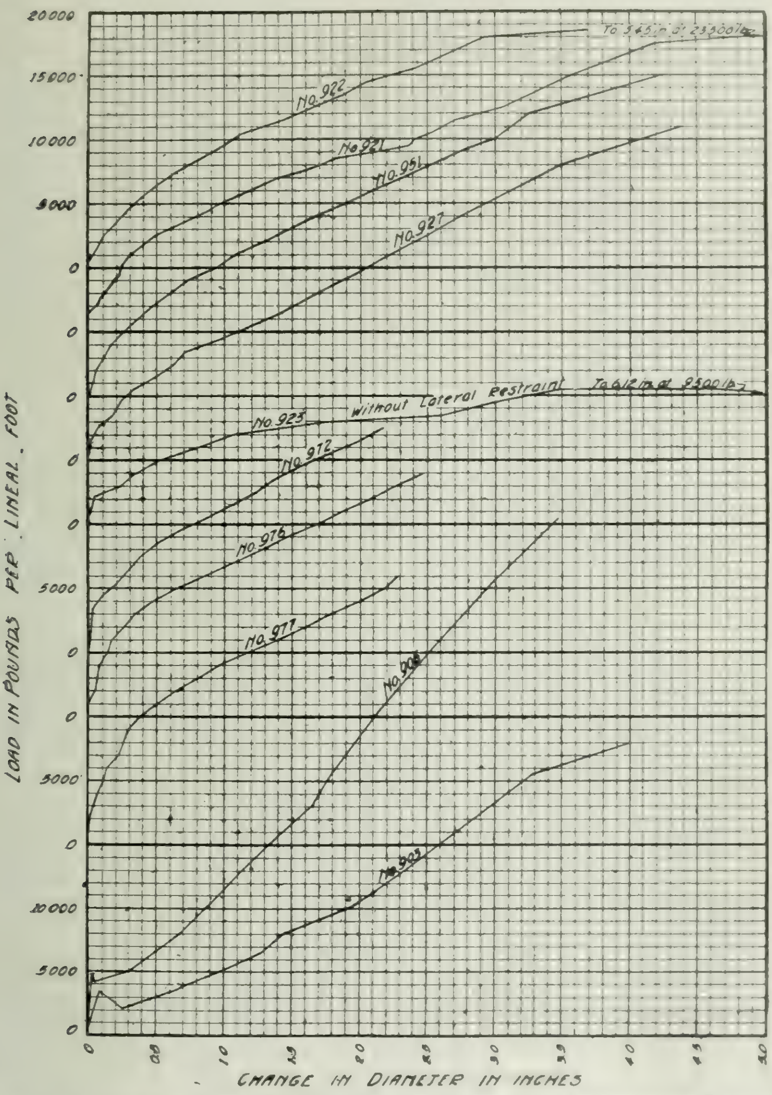


Fig. 19. Load-deflection Diagrams for Concrete and Reinforced Concrete Rings. Distributed Load.

diameters when the test was discontinued. The load-deflection diagrams are given in Fig. 19. The following are notes of the tests of the two plain concrete rings.

No. 903. At a load of 3,550 lb. per lin. ft. and a deflection of 0.09 in., a crack appeared at the bottom and the load dropped off to 2,150 lb. per lin. ft. The indications were that the pressure of the sand of the bed was not well distributed. As the loading head was run down, cracks appeared at the east side of the ring at a load of 2,150 lb. per lin. ft., the crack at the bottom opened to 1/16-in., and a crack formed at the top of the ring. At 2,500 lb. per lin. ft. the crack at the bottom had opened to ¼-in. As the deflections were increased, the indicated load increased, and the cracks at the top, bottom, and sides increased in width, though the amount of the opening of the cracks at the sides could not well be measured. At a load of 8,000 lb. per lin. ft., and a deflection of 1.45 in., the crack at the bottom was 0.5 in. wide and that at the top ¼-in. At 13,000 lb. per lin. ft. another crack appeared at the west side 6 in. above the horizontal diameter, and crushing of the concrete at the extremities of the horizontal diameter became apparent. The crack at the bottom was ¾-in. wide and that at the top ½-in. At 23,000 lb. per lin. ft. a crack appeared on west side somewhat above the horizontal diameter. At 30,500 lb. per lin. ft. the vertical diameter was 3 ft. 7.5 in. and the horizontal 4 ft. 4.5 in. The test was discontinued, although the ring was still taking an increasing load.

No. 906. At a load of 4,800 lb. per lin. ft. and a deflection of 0.03 in. a crack appeared at the bottom. At 4,950 lb. per lin. ft. one appeared at the top. The load fell off to 4,250 lb per lin. ft. At a deflection of 0.3 in. and a load of 5,050 lb. per lin. ft. cracks formed at the sides. These cracks gradually widened as the deflections and loads were increased. A new crack appeared at one side 8 in. above the extremity of the horizontal diameter at 15,500 lb. per lin. ft. and one in a similar place on the other side at 20,500 lb. per lin. ft. The crack at the bottom was ¼-in. wide at a load of 10,500 lb. per lin. ft., 0.5 in. at 30,500 lb. per lin. ft., and ¾-in. at 40,500 lb. per lin. ft. and that at the top was 3/16.—5/8 and 1 in. at the same loads. At the maximum load of 44,000 lb. per lin. ft. there was crushing at the sides, and a circumferential crack formed. The vertical diameter was 3 ft. 8.5 in. and the horizontal 4 ft. 3.5 in.

It is evident that in these tests after the cracks appeared the rings did not act as a single structure but instead formed four pieces under equilibrium somewhat as shown in Fig. 22. Without adequate lateral restraint, equilibrium would not be maintained, and if the elasticity of an embankment failed, stability would be lost. With the lateral pressure maintained, failure occurs by crushing of the concrete.

Distributed Load Tests of Reinforced Concrete Rings.—The tests on the reinforced concrete rings and pipe followed the method used in the tests of the cast iron rings and pipe. The reinforced concrete rings were tested in the small box, using the 600,000 lb. testing machine, and the reinforced concrete pipe were tested in the hydraulic jack machine.

In the reinforced concrete rings cracks appeared early in the test on the tension side at the top and bottom, but the load continued to increase, and from this point to a load of, say 1,500 lb. per lin. ft. the reinforced concrete rings were much stiffer than the plain concrete rings and were evidently acting as reinforced concrete structures. During this stage numerous cracks appeared at the top, bottom, and sides similar to the tension cracks found in the test of re-

inforced concrete beams, and these increased in size. In part of the rings the cracks at the top and bottom increased in width to such an extent as to show failure by the steel becoming stressed past its yield point. In a number of the rings this did not occur but instead the concrete was stripped or split off over the bars by the bars straightening out and pulling away from the interior concrete. In a few cases this was due to poor fabrication, the bars being placed too close to the inner surface, but evidently this feature is a source of weakness in such construction. In No. 972, in which the bars at the top and bottom were made with a much flatter arc, and in No. 976 and 977, in which stirrups were used, stripping of the concrete did not develop and the steel was stressed beyond its yield point. This occurred also in No. 923. In all cases after the yielding of the steel or the stripping of the concrete the action of the ring in the test was much the same as in the tests of the plain concrete rings, and there seems to be no characteristic difference either in the loads or the amount of deflection except that the cracks did not open up wide at the sides and the angular displacement was distributed over a larger number of cracks. This view is borne out by the fact that for this stage of the test the deflections for all the reinforced concrete rings fall (See Fig. 19) between the lines for No. 903 and 906, the two plain concrete rings. It is evident that the action of the ring in the later part of the test is much the same as that of the plain concrete rings in that equilibrium is maintained by the lateral restraint of the sand and that the integrity of the structure is based upon the development and the maintenance of this lateral pressure. The following are notes of the tests.

No. 921. A fine crack appeared at the bottom at 3,500 lb. per lin. ft. at a deflection of 0.14 in., two more at 4,500 and one at top at 5,000 lb. per lin. ft. The concrete began breaking off at the bottom at 5,500 lb. and at the top at 7,000 lb. per lin. ft. The rods broke through and the concrete stripped off at 9,000 lb. per lin. ft. Circumferential cracks appeared at a load of 13,000 lb. per lin. ft. and others appeared at higher loads. Crushing at sides noticed at 16,500 lb. per lin. ft. and was crushing freely at a load of 23,500 lb. per lin. ft., when the deflection was 5.5 in.

No. 922. Fine crack appeared at bottom at 3,500 lb. per lin. ft. and one at top at 3,500 lb. per lin. ft. Other cracks appeared at top and bottom from 4,500 to 6,500 lb. per lin. ft. and at sides at 7,500 lb. per lin. ft. Rods broke through concrete at 12,500 lb. Load continued constant at 18,500 lb.

No. 923. In this test the rods holding the sides of the box were loosened at times, leaving little side restraint. The load then would not increase until there was sufficient increase in the diameter to bring added pressure against the ring. A fine crack appeared at the bottom at 2,250 lb. per lin. ft. and one at the top at 3,000 lb. per lin. ft. Crushing at sides at 8,000 lb. per lin. ft., and circumferential cracks formed. At 10,500 lb. per lin. ft. one rod broke out at bottom. Test discontinued. The large deflection due to this method of testing is shown in Fig. 19.

No. 976. Fine cracks appeared at top and bottom at 4,000 and 6,000 and 7,000 lb. per lin. ft. Three tension cracks finally opened up wide at the bottom and two at the top. No evidence of bars pulling away from the ring. Crushing began at 19,000 lb. per lin. ft.

No. 977. Fine cracks appeared at top at 4,000 and 6,000 lb. and at the bottom at 7,000 lb. per lin. ft., and more at 8,000 lb. Bottom cracks were gradually opening at 9,000 lb. per lin. ft. Failure by tension in steel at top and bottom was apparent at 16,000 lb. per lin. ft. No signs of bars pulling away. Crushing of concrete at 20,000 lb. per lin. ft. Test discontinued at 21,000 lb. per lin. ft.

Distributed Load Test of Pipe.—The results of the distributed load tests of reinforced concrete pipe are quite similar to those of the

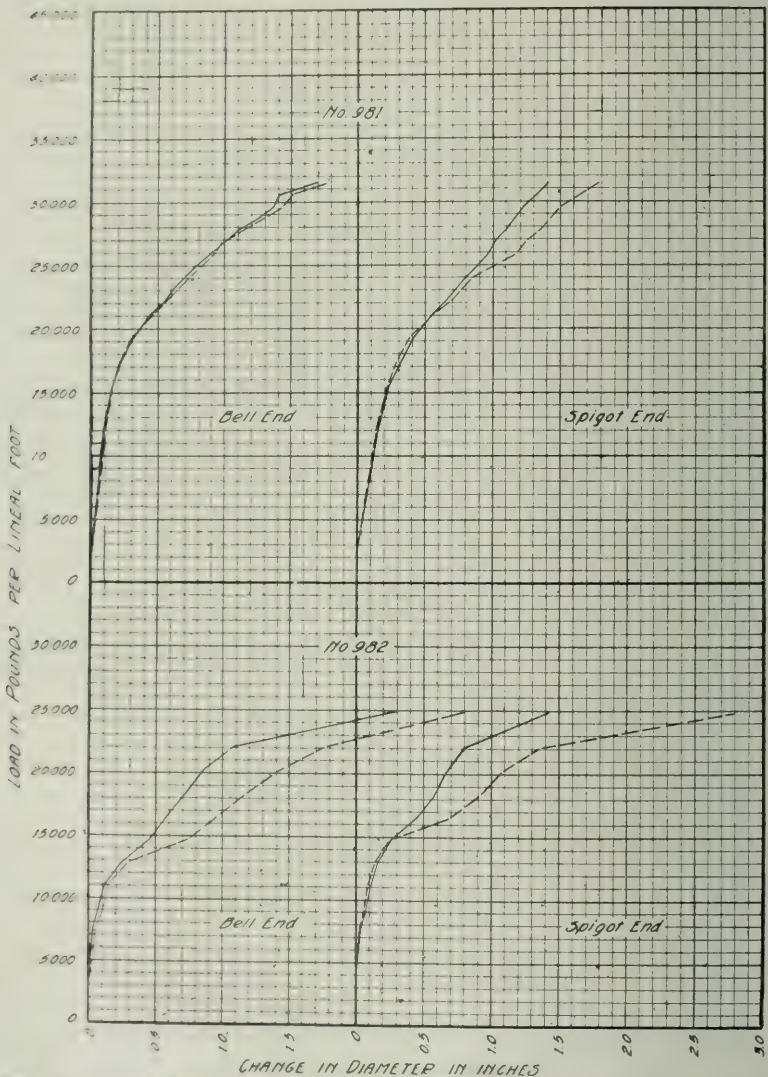


Fig. 20. Load-deflection Diagrams for Reinforced Concrete Pipes. Distributed Load.

tests of rings. Fine cracks became visible on the inner surface at the top and bottom at loads from 5,000 to 11,000 lb. per lin. ft., the amount of the load depending upon the percentage of reinforcement, and numerous fine cracks soon formed. Circumferential cracks appeared at loads somewhat greater, generally next to the bell. At higher loads the cracks became somewhat larger though they did not open up until much later and in several cases in place of tension cracks opening diagonal shear cracks appeared, similar to those found in tests of reinforced concrete beams. There was evidently a change in the character of the load-deflection diagram at this time, and the critical load given in Table 7 is somewhat above the changes here noted. The amount of the deflection of the pipe at the time of the critical load averaged about 0.4 in. In several cases stripping of the concrete from the reinforcing bars at the top and bottom of the pipe occurred as in the tests of rings, but it generally appeared later and was not so serious as in the case of the rings. The action of the pipe at loads beyond the critical load above referred to was quite different from that at previous loads, but the reinforcement evidently acted to hold the concrete together in the four quarters and the pressure was concentrated near the edge at the four quarter points, the pipe being held from total failure by the lateral restraint formed by the pressure of the sand at the sides of the pipe in much the same way as has already been described for the reinforced concrete rings. Crushing of the concrete began to take place at the sides and top at loads near the maximum load, and after the vertical deflections had increased to 3 or 4 inches, this crushing became marked, the load dropped off, and the test was discontinued. Fig. 12 gives views of the condition of the reinforced concrete pipe at the end of the test. The following are notes of the tests.

Pipe No. 981. This pipe, which was reinforced with ¼-in. corrugated bars, was given a preliminary loading in the testing box, the load being applied through I-beams used as levers. The center of the load was placed so that it was 11-in. closer to the bell than was the center of the pipe. In this test cracks first became visible at top and bottom at a load of 8,100 lb. per lin. ft. These cracks extended from end to end of the pipe. Others appeared at top and bottom as the deflection increased, and circumferential cracks appeared in the bell at 11,100 lb. per lin. ft. The loading was increased to 11,600 lb. per lin. ft. at which point the I-beams commenced to buckle and the test was discontinued.

This pipe was afterward tested to destruction in the hydraulic jack machine. This time the load center was 8 in. off the pipe center toward the bell. The cracks above noted reopened and large radial and circumferential cracks appeared in the bell at a load of 18,800 lb. per lin. ft. At 21,500 lb. per lin. ft. one crack in the bottom was quite large from end to end and at 27,000 lb. per lin. ft. crushing of the concrete commenced on the inside. Large pieces fell off the bell, exposing the steel, when 29,700 lb. per lin. ft. was reached, and at 30,600 lb. per lin. ft. the maximum was reached and the test discontinued.

Pipe No. 982. This pipe was reinforced with ½-in. corrugated bars and was 149 days old at the time it was tested. This pipe was heated by steam coils to accelerate its hardening and examination showed that the concrete was somewhat injured thereby. It was loaded 8 in. off the center. At a load of 11,000 lb. per lin. ft. circumferential cracks appeared at top and bottom in the

bell, and hair cracks appeared at top and bottom in the spigot end. The cracks opened up wider as the deflection increased and at 18,500 lb. per lin. ft. crushing commenced inside the bell end, soon extending from end to end of the pipe. At 22,200 lb. per lin. ft. diagonal cracks appeared at top and sides somewhat like shear cracks and soon crushing commenced on both sides about 20° above the horizontal diameter. At a load of 25,000 lb. per lin. ft. the test was discontinued.

Pipe No. 983. This pipe was reinforced with ¼-in. corrugated bars. The load center was 5 in. off the pipe center toward the bell. Tension cracks developed at the top in both ends at a load of 4,900 lb. per lin. ft. and a crack appeared at the bottom at 6,700 lb. per lin. ft. These cracks opened up wider and cracks appeared in the bell at a load of 10,400 lb. per lin. ft. Crushing commenced on both sides at 21,600 lb. per lin. ft. and at 23,400 lb. per lin. ft. the maximum, an average change in the vertical diameter of 3.03 in. was noted, which increased rapidly as the load was held on the pipe.

Pipe No. 987. This test was made with the load 2.5 in. off center. This pipe, which was reinforced with fence wire, cracked end to end at both top and bottom at a load of 4,950 lb. per lin. ft. At 6,800 lb. per lin. ft. radial and circumferential cracks appeared all through the bell. As the deflection increased the cracks opened wider and when a load of 10,500 lb. per lin. ft. was reached, crushing commenced on both sides near the bell and immediately extended end to end of the pipe. The bell commenced breaking away from the barrel at 20,000 lb. per lin. ft. and a maximum was reached at a load of 23,800 lb. per lin. ft. The appearance of this pipe in the latter stages of the test indicated that the load was applied over a small portion of the surface, thus approaching a concentrated load. This may be the explanation of the large deflection found in this test.

Pipe No. 988. This pipe, which was loaded 1.5 in. off center toward the bell, was reinforced with Clinton wire mesh, the wire being No. 3. The first fine cracks appeared in both top and bottom and extended end to end at a load of 6,700 lb. per lin. ft. At a load of 12,300 lb. per lin. ft. the first cracks had opened wider and shear cracks were appearing in the bottom of the spigot end. At 16,000 lb. per lin. ft. shear cracks opened in the top of the bell and tension cracks opened at both ends in the sides of the pipe. Crushing then started on the inside and a maximum was reached at a load of 30,900 lb. per lin. ft.

Comparison and Discussion.—Table 7 gives the loads at the appearance of the first crack, the maximum load carried, a socalled critical load, and a comparison of the critical load with the resisting moment of the pipe or ring acting as a reinforced concrete structure. By the first crack is meant the first crack which was observed, a very fine crack similar to the fine cracks which appear in reinforced concrete beams and which did not interfere with the strength or durability of the structure. The critical load is taken at the point where there is a marked change in the direction of the load-deflection diagram and where it becomes more nearly a straght line. There was at or about this load a noticeable change in the pipe, shown by the tension cracks enlarging or by the shear cracks formed. It seems evident that up to this point the resistance of the pipe is that of a reinforced concrete beam and that beyond this critical load the action of the reinforcement is principally to hold the parts of the ring together and the main resistance is the compressive strength of the concrete at the top, bottom, and side points against pressure induced by the arch action made by the lateral pressure and restraint of the sand at the sides. This view is corroborated by the amount of de-

flection and by the similarity of action and of deflections in the tests of the Jackson pipe and of the plain concrete rings. The column headed t gives the average distance from the center of the reinforcing bars to the compression face of the concrete at the top and bottom. No allowance has been made in the calculations for the greater size and stiffness of the bell. The column headed M′ gives the bending mo-

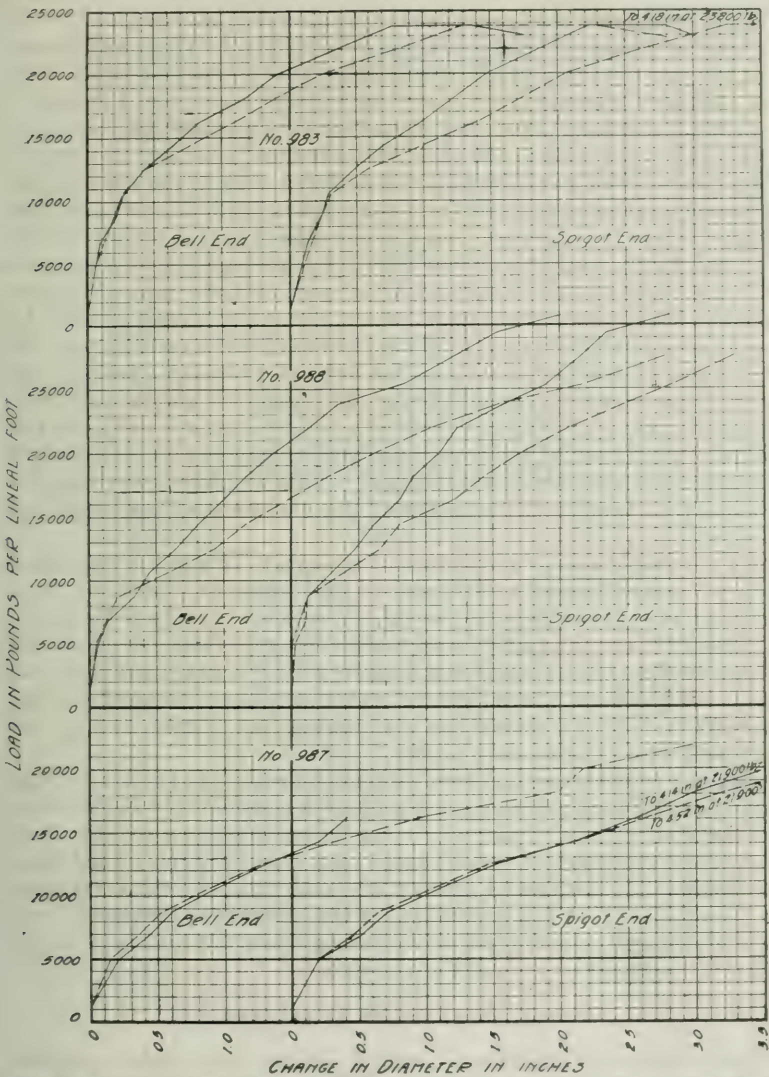


Fig. 21. Load-deflection Diagrams for Reinforced Concrete Pipes. Distributed Load.

ment calculated from the critical load on the basis that the load is evenly distributed over the horizontal section and that there is no side restraint. The column headed Mo gives the resisting moment as a reinforced concrete beam by the formula 0.87 A. f t and is based upon the strength of the steel at its yield point as the controlling element. A is the area of the reinforcement in a length of pipe of 1 foot, t is the distance from the center of the reinforcement to the compression face of the concrete and f is the strength of the steel at the yield point, which is here taken to be 46,400 lb. per sq. in. for the rings and 55,000 lb. per sq. in. for the pipe. For the condition that the reinforced concrete fails by the tension of the steel at its yield point, that the load is uniformly distributed over a horizontal section and that there is no lateral restraint, the ratio of the two moments should be unity. If the resisting moment due to the steel is not developed, as in the case of No. 982 where a large amount of reinforcement is used, this ratio will be greater than unity. In case that there is side restraint the effect will be to reduce the ratio to an amount less than unity, provided both the horizontal pressure and the vertical pressure are uniformly distributed. For these conditions the amount of the ratio should be 1—q as given in equation (5). That is to say, if the ratio is 0.75 the lateral pressure would be 25% of the vertical pressure. In case the load is not uniformly distributed over the horizontal section this relation would not hold and the tendency of any concentration of the load near the center of the top of the pipe would be to give a larger ratio than would otherwise be found. This is complicated by the probability of uneven distribution of the loads along the length of the pipe.

It is noticeable that No. 982 has a high ratio. This is the pipe with the large percentage of reinforcement and made of concrete which seems to have been injured in curing. With this exception the ratios are generally less than unity and their average, is not far from the average found in the distributed load tests of the cast-iron pipe and rings. Ring No. 923 in which the rods were kept loosened so that there was no lateral restraint has a somewhat higher ratio and agrees fairly well with the calculated value.

After the critical load has been passed the reinforced concrete ring will, under the conditions of the test, bear a considerably higher load than the critical load, though it must be understood that this load comes after the reinforcement ceases to act as in a reinforced concrete beam, that the cracks formed are such that the reinforcement may be exposed and the durability of the structure threatened, and that the strength of the pipe is dependent upon the maintenance of the lateral restraint of the sand at the sides.

GENERAL COMPARISON OF RESULTS.

Comparison of Methods of Loading.—The tests under concentrated load for both the cast-iron and the reinforced concrete rings gave results which are consistent with analysis, both as to strength

of the rings and as to the nature of the deflection curves and the amount of the deflection. The cast-iron rings broke suddenly, but the reinforced concrete rings (as shown in Fig. 19) maintained the maximum load until the deflections had increased materially. It is evident that the reinforced concrete structure may be deflected much beyond the amount which is produced by the critical load before final failure results.

In the discussion of the tests under distributed load for both the cast-iron pipe and the reinforced concrete pipe, it was noted that the determination of the resistance of the pipe to distributed load is much complicated by the uncertainty in the distribution of the load and in the amount of lateral pressure which may be developed. It is worth while, however, to make a discussion of the observations and calculations to see what conclusions may be drawn. In Table 4 already referred to, are given values of the bending moment and resisting moment developed in the cast-iron pipe, and in Table 7 values of these moments for the reinforced concrete pipe. As has already been noted, the expression used for the bending moment, 1/16 Wd, is based upon the assumption that the load is uniformly distributed over the horizontal section both longitudinally and transversely, and also that there is no lateral restraining pressure. The value of the resisting moment in Table 4 is based upon the modulus of rupture determined from the tests of the cast-iron rings under concentrated load. The value of the resisting moment of the reinforced concrete pipe in Table 7 is based upon the ordinary formula for strength of a reinforced concrete beam at the yield point of the reinforcement and does not consider that failure by diagonal shear or other cause may occur earlier.

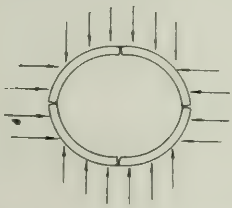


Fig. 22. Action of Unreinforced Pipe under Distributed Load.

Under the above assumptions the ratio of the resisting moment to the bending moment developed, as given in the above table, should be unity. If a lateral pressure acts the ratio should be less than unity and its value would correspond to the 1—q of equasion (5). If the lateral pressure is 25% of the vertical pressure, both being assumed to be uniformly distributed, the ratio would be 0.75. If, however, the load is not uniformly distributed over the horizontal section the effect would be to give a larger ratio in the calculations made than would be found if the actual distribution of the load were known and used. The effect of the bell itself may possibly make

the resisting moment of the pipe smaller than is assumed in the tables.

The average value of the ratio in the table for the cast-iron pipe is somewhat less than unity. It has been suggested that the higher values of this ratio may be due to uneven bedding and distribution of the load and this is borne out by some of the observations of the test. The lower values of the ratio indicate the presence of considerable lateral pressure, and the effect of no lateral pressure upon deflections is quite apparent in the test of cast-iron pipe No. 990 and in the reinforced concrete ring No. 923 where the horizontal restraining rods were kept loosened.

Evidently there is more or less variation in the conditions of the test and probably also in the resisting strength of the pipe. In the reinforced concrete rings and pipe the selection of the critical load given in Table 7 is dependent somewhat upon judgment,but the values have been compared with the conditions in the concentrated load tests and changes which may be made by different individuals would not affect the results materially. The value of the ratio of the two moments is seen to be quite similar to those given in the table for the cast-iron pipe, and its average is under unity. Evidently the conditions relating to the distribution of load and the effect of the lateral pressure are similar to those found in the test of cast-iron pipe. For high percentages of reinforcement or with steel of a high elastic limit, like drawn wire, the pipe is likely to fail by other forms of failure than through the steel being stressed beyond its yield point.

In the reinforced concrete pipe beyond the so-called critical load the action of the structure, as has already been stated, is quite different and the final failure is through crushing of the concrete. It would seem that this strength is available in an emergency, though the condition of the concrete in reference to cracks and defects may be such as to affect the durability of the structure.

Measure of Strength of Pipe.—From these tests it seems evident that the lateral restraint is considerable and that the pressure exerted at the sides aids considerably in holding the pipe from large deflections and thus strengthens it materially, but at the same time the apparent effect of this is largely counteracted by the lack of uniformity in the distribution of the load and the lateral pressure, which results in making the bending moment of he vertical load larger than the assumed moment reduction in the ratio 1—q below unity which may be found in the tests may be considered to be merely an added safeguard. It will probably be best then to use 1/16 Wd for the bending moment coming upon such a pipe when the bedding and lateral filling is well done, considering any reduction in the ratio of moments here discussed only as a margin of safety. In case of careless or indifferent bedding or filling the lack of uniformity of distribution of pressure transversely and longitudinally will require that a higher bending moment than 1/16 Wd be used.

The strength of cast-iron pipe may be calculated by using in the expression for resisting moment, a value of the modulus of rupture, say, 25% less than the modulus of rupture obtained by breaking small beam test specimens of the same metal. The effect of the presence of the bell is somewhat uncertain but it is quite probable that greater strength could be obtained by distributing the metal of the bell throughout the barrel of the pipe. It should be noted, too, that it is probable that the quality of the cast-iron pipe tested was better than the ordinary run of cast-iron culvert pipe, used by railroads. In the tests the cast-iron pipe failed at the maximum load and the load sustained dropped off suddenly, indicating that there would be a complete collapse under a dead load.

The critical strength of reinforced concrete culvert pipe where the reinforcement does not exceed, say, 0.75 of 1% and is of medium steel may be measured by the resisting moment calculated by the ordinary beam formula. This, of course, is with good concrete. The resistance against diagonal tension and stripping of the concrete over the bars may be improved by flattening the arc around the top and bottom and possibly by the use of strirrups at these points. The actual load which the reinforced concrete pipe will take above this critical load is a great safeguard. The property which a reinforced concrete beam has of holding a load near its maximum load through a considerable deflection may be of great value in case the earth at the sides yields and the pipe must follow it to get the benefit of side restraint.

Loads and Failures.—The distributed load tests herein described were made with the filling of sand carefully placed and packed. It is evident that the condition of the bedding and filling and also the nature of the materials used in filling over the pipe will have a great influence upon the amount of the load and upon its distribution. The experience in the breaking of vitrified pipe sewers is analogous. Many cases of breakage of lines of pipe sewer have been reported in diameters from 18 in. upward. These instances have occurred in rock and clay more generally, though such failures are found in sand and quick-sand. The load which will come upon such sewer pipe from the trenches will vary with the manner of filling and the nature of the soil, as has already been suggested. Failures of cast-iron pipe under high embankments have been reported. In some of these cases the loose rock which was used for filling produced high loads. The effect of the manner of filling and of the nature of the material and the cause and prevention of such breakages would make a long paper by themselves. It is hoped, however, that the discussion of this paper will bring to light instances of the failure of culvert pipe with sufficient data to throw light upon the loads which were produced by the embankment. If engineers will report the circumstances attending such failures, the height of the embankment, the condition of the bedding, the nature of filling, the nature of the materials placed in the filling, and the time which had elapsed after

construction the information will be very helpful in planning new structures, particularly where new types of construction like concrete and reinforced concrete are to be used. Such data will add much to the information given in this paper.

TABLE 1.

Mechanical Analysis of Gravel Used in Reinforced Concrete Culvert Pipe.

	PER CENT PASSING			
Sieve No.	Test No. 1	Test No. 2	Test No. 3	Average
3/4	90.5	93.8	91.0	91.8
1/2	77.1	81.5	78.1	78.9
3/8	63.0	68.4	65.8	65.7
3	50.7	58.0	55.0	54.9
5	35.4	43.7	40.2	39.8
10	33.4	41.5	38.3	37.7
12	33.1	41.1	37.8	37.3
16	32.0	40.4	37.2	36.5
18	31.7	39.4	36.1	35.7
30	29.6	36.1	32.9	32.9
40	23.4	28.4	26.0	25.9
50	9.0	10.5	10.1	9.9
74	5.1	6.4	6.0	5.8
150	1.3	1.9	1.7	1.6

TABLE 2.

Lab No.	Internal Diameter inches	Thickness Range inches	Thickness Average inches	Length over all inches	Furnished by
			CAST IRON PIPES.		
990	48		1.25	80	I. C. R. R.
991	48		1.25	99	C. M. & St. P. Ry.
992	48		1.25	99	C. M. & St. P. Ry.
993	48		1.50	101	C. R. I. & P. Ry.
994	48		1.50	96	C. R. I. & P. Ry.
995	36		1.00	96	A. T. & S. F. Ry.
996	36		1.25	96	A. T. & S. F. Ry.
997	36		1.00	96	A. T. & S. F. Ry.
998	36		1.25	96	A. T. & S. F. Ry.
			CAST IRON RINGS.		
991A	48		1.4	24	C. M. & St. P. Ry.
991B	48		1.25	24	C. M. & St. P. Ry.
992A	48			24	C. M. & St. P. Ry.
992B	48	1.31-1.25	1.28	23	C. M. & St. P. Ry.
993A	48	1.47-1.35	1.43	24	C. R. I. & P. Ry.
993B	48	1.50-1.34	1.42	24	C. R. I. & P. Ry.
994B	48	1.63-1.53	1.58	24	C. R. I. & P. Ry.
994C	48		1.6	24	C. R. I. & P. Ry.
995A	36	1.13-0.90	1.02	24	A. T. & S. F. Ry.
995B	36		1.1	24	A. T. & S. F. Ry.
996A	36		1.44	24	A. T. & S. F. Ry.
996B	36	1.50-1.27	1.42	24	A. T. & S. F. Ry.
997A	36		1.00	24	A. T. & S. F. Ry.
997B	36	0.98-0.82	0.91	24	A. T. & S. F. Ry.
998A	36		1.25	24	A. T. & S. F. Ry.
998B	36	1.31-1.05	1.19	24	A. T. & S. F. Ry.

TABLE 3.

Cast Iron Rings—Concentrated Load.

No.	Breaking Load lb. per lin. ft.	Modulus of Rupture	Modulus of Elasticity	Remarks
991A	16,250	32,600	11,000,000	Failed at top.
991B	10,300	26,000	12,700,000	Failed at bottom.
992B	11,720	27,300	9,700,000	Failed at top.
993B	12,850	25,200	7,780,000	Failed at bottom.
994B	17,400	27,600	8,300,000	do
994C	16,500	25,500	8,600,000	Failed at top.
995A	9,650	27,500	10,200,000	Failed at bottom.
995B	13,500	24,000	14,300,000	Failed at top.
996A	17,500	33,300	11,840,000	Failed at bottom.
996B	18,500	26,800	8,800,000	do
997A	6,950	20,600	6,500,000	Failed at top.
997B	6,650	21,800	10,900,000	Failed at bottom.
998A	17,500	33,300	12,400,000	Failed at top.
998B	13,100	23,800	9,700,000	Failed at bottom.

TABLE 4.

Cast Iron Pipe and Rings—Distributed Load.

No.	W Load at 1st Crack lb. per lin. ft.	W^1 Breaking Load lb. per lin. ft.	M_1 $\frac{W^1 d}{16}$	M_0 $\frac{fbt^2}{6}$	Ratio $\frac{M_0}{M^1}$
		PIPES.			
990	26,700	37,500	115,000	85,600	0.74
991	22,600	26,400	81,000	102,000	1.26
992	16,300	22,600	69,000	92,300	1.34
993	34,600	54,600	169,000	102,000	0.60
994	47,300	49,300	152,000	134,000	0.88
995	19,300	22,200	52,000	57,800	1.11
996	37,300	37,300	87,000	110,000	1.26
997	25,200	27,300	63,000	38,200	0.61
998	29,300	37,200	86,000	93,400	1.08
		RINGS.			
992A	22,150	22,150	68,000	92,500	1.36
993A	29,250	29,250	90,000	104,000	1.16

TABLE 5.

Concrete and Reinforced Concrete Rings and Pipe—Data of Tests.

No.	Age at Test Days	Manner of Loading	Critical Load lb.	Maximum Load lb.
		RINGS.		
901	37	Concentrated		5,000
902	36	Concentrated		3,900
907	40	Concentrated		5,600
908	35	Concentrated		5,200
911	42	Concentrated		3,000
912	41	Concentrated		4,200
903	36	Distributed	7,100	61,000
906	34	Distributed	9,600	88,000
926	32	Concentrated		5,700
928	44	Concentrated		7,100
931	31	Concentrated		5,000
932	37	Concentrated		6,000
933	34	Concentrated		6,350
934	98	Concentrated		6,300
952	36	Concentrated		4,700
953	45	Concentrated		7,200
971	93	Concentrated		8,250
923	36	Distributed	14,000	21,000
921	41	Distributed	20,000	47,000
922	38	Distributed	20,000	37,000
927	36	Distributed	16,000	52,000
951	38	Distributed	18,000	50,000
972	88	Distributed	16,000	35,000
976	92	Distributed	18,000	38,000
977	90	Distributed	20,000	42,000
		PIPES.		
985 & 6		Distributed		200,000
981		Distributed	166,000	268,000
982	149	Distributed	129,000	215,000
983	118	Distributed	106,000	202,000
988	183	Distributed	76,500	262,000
987	92	Distributed	76,500	[illegible]

TABLE 6.

Concrete and Reinforced Concrete Rings.

No.	Load at 1st Crack lb. per lin. ft.	Maximum Load lb. per lin. ft.	t inches	Modulus of Rupture	M 0.16 Wd	M_0 0.87 Atf	Ratio $\frac{M_0}{M^1}$
			CONCRETE RINGS.				
901	2,500	2,500	6	300			
902	1,950	1,950	6	234			
907	1,900	1,900	6	228			
908	2,300	2,300	6	276			
911	1,500	1,500	6	180			
912	2,100	2,100	6	252			
			REINFORCED CONCRETE RINGS.				
926	1,500	2,850	2.75		23,700	26,600	1.12
928	1,400	3,550	2.5		29,500	24,200	0.82
931	2,150	2,500	2.75		20,800	26,600	1.28
932	1,500	3,000	3.0		25,000	29,100	1.16
933	1,170	3,170	2.0		26,400	19,400	0.73
934	1,300	3,150	2.5		26,400	24,200	0.92
952	1,000	2,350	2.0		19,600	19,400	0.99
953	1,200	3.600	2.25		29,900	21,800	0.73
971	1,500	4,120	2.75		34,500	26,600	0.77

TABLE 7.

Concrete and Reinforced Concrete Rings and Pipes.

No.	Load at 1st Crack, lb. per lin. ft.	Critical Load, lb. per lin. ft.	t inches	$\frac{M^1}{16} Wd$	M_0 0.87 Atf	Ratio, $\frac{M_0}{M^1}$	Maximum Load, lb. per lin. ft.
			CONCRETE RINGS.				
903	3,550						30,500
906	4,800						44,000
			CONCRETE PIPE.				
985 & 986	2,000						40,000
			REINFORCED CONCRETE RINGS.				
923*	2,250	7,000	2.50	22,700	24,200	1.06	10,500
921	3,500	10,000	2.50	32,500	24,200	0.74	23,500
922	3,250	10,000	2.50	32,500	24,200	0.74	18,500
927	3,250	8,000	2.50	26,000	24,200	0.93	26,000
951	3,200	9,000	2.50	29,200	24,200	0.83	25,000
972	4,500	8,000	2.75	26,000	26,700	1.03	17,500
976	4,000	9,000	3.00	29,200	29,000	0.99	19,000
977	4,000	10,000	3.00	32,500	29,000	0.89	21,000
			REINFORCED CONCRETE PIPES.				
981	8,360	19,500	3.00	63,500	34,700	0.55	31,500
982	10,960	15,000	3.00	48,800	72,600	1.49	24,800
983	4,950	12,500	3.00	40,600	34,700	0.86	23,800
988	6,700	9,000	3.00	29,200			31,400
987	4,950	9,000	3.00	29,200			23,800

*No lateral restraint.

DISCUSSION.

President Lowe‌th: Prof. Talbot's paper is certainly interesting and instructive, and contains a great amount of information not found, so far, in engineering literature. There seems to be a dearth of reliable data about the strength of large pipes under actual conditions,— iron pipes and especially concrete pipes. There is a great deal of valuable information in this paper, and it is now before you for discussion.

Mr. C. H. Cartlidge, M.W.S.E.: This is a subject in which I am very much interested, and while Prof. Talbot has stated very truly that the question of cost is one which did not properly enter into his paper, I think it is very pertinent to the subject as a whole. The aim of every maintenance engineer on the railroad is to do the work that has to be done as well and as cheaply as possible. It occurred to us, on the C. B. & Q. R. R., sometime ago, that we were paying a good deal of money for cast iron pipe. Our experience with cast iron pipe has been somewhat variable; in other words, sometimes we have been very successful in its use, and at other times we have had failures of the most unexplainable kind. At one time there was in force a rule to the effect that only the heaviest cast iron water pipes were to be used for culverts under the banks, but that no such pipes were to be used in banks under 10 ft. or over 25 ft. in height because of their liability to break. I cannot vouch for the necessity of that

provision, however. At any rate I know that many cast iron pipes on the C. B. & Q. R. R. have been broken. In conversing with one of the engineers on the C. R. I. & P. Ry., he told me that he had never seen a failure of a cast iron pipe. I will not undertake to explain here why there should be this difference, but on the "Burlington" road there are very bad conditions physically. A large part of the Road runs through a farming country, where the soil is clay, with very little rock. A great deal of it lies in flat, marshy bottom, with black alluvial soil, and the track is built on high embankments. We have found that in many cases the cast iron pipe failed within a month after being put under these high embankments. Some of these failures may have resulted from careless bedding. We have never had any substitutes for cast iron pipe which would stand the work, until we tried reinforced concrete. We developed this idea rather empirically and did not attempt to make any calculations of the strain, but we have had no failures. The concrete was put in, in some places under the same conditions as the cast iron pipe was put in, and the cost was much less. With the small sizes of pipe—2 ft. or somewhat less—there is not much difference in price. With 4 ft. pipe, the cost is about one-half the cost of cast iron pipe. On the Burlington road about 15,000 ft. of cast iron pipe has been used per year, in replacing bridges, and as any road the size of the Burlington in the west probably used about the same amount, we may assume an average saving of about one-half, which is an item of considerable interest to a maintenance engineer.

I desire to say, in regard to the tests of pipe made at the University of Illinois, that only two of the concrete pipes can be said to fairly represent the pipe we are using. The others were entirely experimental. One of the experimental pipes was made in the winter time. In order to expedite the seasoning of this pipe for the test we heated it, and very nearly ruined the concrete. The other pipe was reinforced with a wire mesh and it broke, (with very high deflections) under comparatively low load. We are now making, near Montgomery, a better pipe, I think, than any we have tested, on which we expect to make some further tests.

The method of "curing" the pipe seems to have a great influence on its strength. By keeping it covered in summer we get a better concrete than we are able to get by leaving it out in the open.

President Loweth: Will Mr. Cartlidge say whether he has in mind the present low price of cast iron pipe in making his comparison of costs? Cast iron pipe can be bought today for about 65 per cent. of the ruling price of eight months ago, and while there has been a large decrease in the price of the cement and labor entering into the cost of concrete pipe, the speaker doubts if it has been as great, relatively, as for cast iron pipe.

Mr. Cartlidge: In making that comparison I assumed the price of cast iron pipe at $26.00 per ton, and the price of cement at $1.00 per barrel.

President Loweth: Did the cast iron pipe break crosswise or crush?

Mr. Cartlidge: The last view shown on the screen was a diagram of a pipe cut in four sections and represents a typical failure of a cast iron pipe, except that, in many cases, it broke in more than four pieces.

President Loweth: What was the proportion of cement used?

Mr. Cartlidge: We used 1:4-½ mixture, Portland cement and gravel.

Mr. R. J. Mershon, M.W.S.E.: The test made at the University of Illinois on "cast iron and reinforced concrete culvert pipe" has interested the writer somewhat on account of some experience he had some years ago. It seems to him, that the tests made at the University of Illinois are not altogether practical, for the conditions under which the tests were made. The pipe was put through a machine with some similarity, of course, to similar conditions.

Pipe embedded in the ground has an elastic bed to rest upon, and for any vertical pressure there is a corresponding and proportional pressure laterally, and all around the pipe if properly laid. Let us suppose, for instance, that any length and size of pipe be laid in thirty-two feet of water, which represents one atmosphere, or about fifteen pounds to the square inch of vertical pressure, then there will also be an inward pressure of fifteen pounds to the square inch on the sides of the pipe and all around it, which conditions the testing machine did not give as used. The same principles are true with any loose, even soil that is well tamped around any tubing, pipe or brick work, for if any sudden addition or vertical pressure is transmitted to the soil about it there is at once a corresponding lateral pressure on the sides of the pipe, provided the pipe has been properly laid and the soil well tamped.

Of course, you may say, the soil is not free to move its particles like water, but for any lack in that, it favors the strength of the pipe by the soil wedging and arching over the pipe, which is true in all cases where tamping and laying of the pipe has been fairly done. The pressure over a pipe in an embankment represents an isosceles triangle or arch with the width of the trench for its base.

I think, by experience, I am borne out in this by the 15 in. 18 in. and 24 in. pipes laid under the "Rock Island" and "Panhandle" railways some twenty years ago, with so little covering and are intact yet and can be seen. Those same pipe, if put in the University testing machine, under like conditions, or the 10½ foot, three ring brick sewer on Wentworth Ave, with a forty foot cut, would not hold up the saddle, to say nothing of hydraulic jacks; but such tubing does stand and has stood for a lifetime with only the soil for reinforcing, and are crossed and re-crossed by the heaviest trains many times a day. It still seems to the writer that the reinforcing of concrete pipe, either one foot or four feet in diameter is not necessary, or the use of cast iron pipe unless in some unusual case. A 24 in. diameter

"Akron" pipe is $1\frac{1}{4}$ in. thick, and is considered by the company strong enough for any embankment, if well laid, but a 48 in. diameter pipe is another proposition unless much thicker. A 12 in. Akron sewer pipe is $\frac{7}{8}$ inches thick; a 15 in. is 2 in. thick; a 24 in. single strength is $1\frac{1}{4}$ in. thick, and for a 48 in. pipe about $2\frac{1}{2}$ in. thick will do. This thickness for a 48 in. pipe is based on the thickness of well tubing that has stood for years under a 60 foot bank pressure. Professor Rankine gives the tensile strength of cement at 280 lbs. per sq. in.—this would give for a 48 in concrete pipe, two feet long and properly made, 4,800 pounds.

Loose damp sand well tamped, will bear safely 30 lbs. per sq. in. sand loam 45 lbs. and clay 60 lbs. this pressure of 30 lbs. for damp sand well tamped, would give 50,000 lbs. for lateral pressure which is almost exactly twice the breaking strength of 4 ft. cast iron pipe given in Mr. Talbot's tables. The writer thinks that every pipe and brick sewer in Chicago will bear out the fact that reinforcing of concrete pipe up to four feet in diameter is not necessary, nor the use of cast iron pipe, so far as breaking strength is concerned, under vertical or lateral pressure.

Often for lack of proper help or time, such work is turned over to the section men with a short visit from the roadmaster, with cramped places to work in and pipe of any kind tumbled in almost any way with ballast and cobble stone dumped against the pipe.

It seems that more practical tests could have been made at the University with the same material by constructing a larger box, putting three or four foot of dirt under the pipe and at the sides and from one to six or eight foot over it, well tamped around the pipe, then put the pressure on and we would have more nearly the natural conditions, and the plain pipe would no doubt have given good results.

Mr. A. S. Baldwin, M.W.S.E.: It is very interesting to note that we shall be able to get a reinforced concrete pipe that we may believe will be quite as efficient as cast iron pipe and at a price considerably less. There are, pertaining to the reinforced concrete pipe, many of the advantages that pertain to concrete construction of any other character. The sections of pipe as built are comparatively short—that is, as compared with cast iron—and consequently very much more economically and easily handled. This is of great advantage where the transportation is over a long distance and through a difficult country. Also, it will be possible to construct the reinforced concrete pipes on the ground, where it would be almost impossible to transport cast iron pipe and where the materials for concrete construction can be transported very rapidly and easily. I have had experience in endeavoring to transport cast iron pipe in a rough country, and in some cases it is a much more difficult matter than many people imagine.

Consideration should be given to the fact that a large amount of cast iron pipe is broken in transit. Around any material yard of a new road under construction, at the points of delivery, and along the

route you will frequently find many sections of pipe broken in transit.

In comparing the cost of concrete pipe with cast iron pipe, the question of length is a factor, because, if it is impossible to handle very long sections of cast iron pipe, then the shorter sections become more expensive. There are today, at several points I know of, manufacturers who make cast iron pipe especially for culvert purposes. The cost per ton of such pipe is much greater than the ordinary water pipe that can be purchased, and consequently it would be fair, in comparing costs, to take those features into consideration; when this is done the result is even more in favor of the concrete pipe.

An interesting thought brought up by the diagrams given by Professor Talbot, is the manner of trenching for cast iron pipe. I suppose most of us have had experience with having cast iron pipe break under the banks. As a rule, when they break they would not, under ordinary conditions, be subjected to a pressure that would justify their breaking in a great majority of cases, due to the unequal loading of the pipe, the result being that of course the pipe is subjected to undue stress in certain lines, and a fair comparison is not obtained when considered in connection with equal loading.

The best form of trench to dig for pipe of any character, whether cast iron or reinforced concrete, is a matter of considerable interest. I have found it very difficult to have the trench made to suit the pipe. It is almost impossible to have a semi-circlar trench dug. For example, if the trench is dug as the ordinary laborer will dig it, you get a very unequal pressure upon the pipe, and I have found that as a rule the best results are had by making the trench semi-circular with a larger hole than the pipe and then carefully tamping it from the bottom up, after the pipe is placed. It is to be borne in mind too, that longitudinally, with the pipe as it lies under the embankment, it is very difficult at times to get an even bedding and one that is straight. Generally the pipe lies on a sloping surface, and that surface has been cut unequally, and in an endeavor to get a trench down to a true gradient, the result is the lower part of the pipe is apt to go under the drainage. I shall be glad to have some light on what would be the relative value of the reinforced concrete pipe and the cast iron pipe in case of an unequal loading. That is, in case the two ends of the pipe were supported and there was an excessive load in the middle, for that is the test that the pipe is most apt to be put to.

Professor Talbot: I do not know of any tests which would answer the question. Of course cast iron pipe has its full strength as a beam longitudinally, and that strength may easily be calculated. The beam strength of reinforced concrete pipe would depend on the amount of the longitudinal reinforcement. If that is considerable, it ought to have sufficient strength for the purpose. I think no general answer could be made to Mr. Baldwin's inquiry.

Mr. Baldwin: Have you considered the question of longitudinal reinforcement?

Professor Talbot: Not for this purpose.

President Lowcth: The question has been asked, why not make concrete pipe without reinforcement? This could easily be done, but such pipe, if equally strong, would be so heavy it would be much more difficult to handle.

Mr. W. E. Wood, M.W.S.E.: I will ask Mr. Cartlidge whether or not he finds it necessary to put shores in his concrete pipe when used under high embankments, the same as with iron pipe?

Mr. Cartlidge: Yes, that is our rule.

Mr. Wood: I have never had much experience with concrete pipe, but have had considerable experience with iron pipe ever since their first use for culverts, on the C. M. & St. P. Ry. We found that a great many of the larger sized iron pipes broke, especially under high embankments, where fresh filling was placed directly upon the pipes as in filling a bridge which was replaced by an iron pipe culert, even though this filling had been carefully placed and well tamped around the pipe.

We put shores in the larger pipes and leave them in for two or three years until the banks become somewhat settled, and the earth forms a sort of natural arch over the pipe. I remember one case in particular, before shores were used, where a 48 in. diameter iron pipe was put in to replace a timber bridge about 40 or 45 ft. high. The pipe was carefully laid and the earth was well tamped around the pipe by bridge men. The filling was done with wheel scrapers and teams. Shortly after the filling of the bridge was completed, cracks began to appear at the top and bottom of the pipe in the sections of pipe directly under the center of the bank, and the pipe finally broke into four pieces, just as has been shown in Professor Talbot's diagrams, the breaks being at the top and bottom and at each side of the pipe. So that I believe shores are necessary in cases of this kind, to prevent failure of the pipe.

We have found very few broken pipes where they replaced old wooden box culverts, in which the original embankments were not disturbed to any great extent.

Mr. Cartlidge: There is one feature in connection with reinforced concrete pipe that has not been touched on this evening. I think everybody will agree that if you will tie the concrete together with iron rods or wire mesh, or with expanded metal, there is less liability of its being distorted to so great an extent as if it were not so tied together. We will assume that the reinforced concrete pipe is going to break under the same load as plain concrete pipe; we then have, in addition to the resistance power, whatever there is in that reinforcement to hold those broken parts together. I think that amounts to a good deal, and it is worth considering in that connection.

President Lowcth: That point was plainly brought out in one of the diagrams, where some of the rings which were not reinforced, had only about one-third of the strength of the reinforced concrete rings.

Mr. E. N. Layfield, M.W.S.E.: It may be worth while to call at-

tention to the fact that it is quite gratifying to note that those pipes behaved, under these tests, as it was calculated they should behave.

Mr. T. L. Condron, M.W.S.E.: Mr. Cartlidge's last remarks brought to my mind the thought that there was a certain amount of distortion demonstrated in the reinforceed concrete pipes that was not possible in either the cast iron or plain concrete pipes. Therefore, as the pipe had its load come on it and the vertical diameter was shortened and the horizontal diameter lengthened, one would naturally find, by that condition, that the side pressure would be increased or the pipe would receive greater support from the sides as its horizontal diameter lengthened. A pipe which could be somewhat distorted without breaking would, for that very reason be able to develop much greater strength than if it could not distort without rupture. This probably accounts for some of the very satisfactory behavior of the reinforced concrete pipe in service.

Mr. A. Reichmann, M.W.S.E.: The diagrams of the cross sections of the pipe clearly emphasizes the careful consideration which has been given to the using of materials for which they are best adapted. The steel being used in tension and the concrete in compression, for which purpose it serves very well, and in that way by far more economical results are obtained than by the use of cast iron for pipe purposes, as the strength of the cast iron pipe is determined by the tensile strength of cast iron which we know to be an uncertain quantity; besides, the concrete protects the steel from rust, and the concrete itself is far more durable under ground that iron unprotected. The careful investigation of the uses of various materials for purposes to which they are most adaptable in recent years, has very materially changed our methods of construction in many cases. It has greatly eliminated the use of cast iron for structural purposes and instead either steel or reinforced concrete is being used.

Mr. Baldwin: I would ask if any of the gentlemen present can give any information regarding what are the actual effects of the loading that the pipes are generally subjected to in embankments? I was told by the Chief Engineer of a prominent railroad company several years ago that he had used cast iron pipe to a large extent on a road where the fills were not excessively high but the supporting ground a soft, alluvial soil. The cast iron pipe broke and had to be taken out. He said that in every case careful measurement showed that the cast iron pipe had become elliptical, indicating an excess of vertical pressure.

Mr. Cartlidge: That is a point that I intended to cover in my remarks. The soil on the Burlington Road is largely such as Mr. Baldwin calls alluvial. The majority of our breaks were in soil of that character, but the banks were generally very high.

Mr. G. T. Bunker, M.W.S.E.: A few days ago I read in one of the technical papers a short article about steel culvert pipe, and the statement was made that a pipe is now being made of corrugated shape similar to corrugated boiler tubes. The corrugations seemed to add

considerably to the strength of the pipe, as made specially for culvert purposes. The article gave an instance of some tests where the pipe was put close under the ties, (within three or four inches), and was subjected to very heavy loads. The results of the tests seemed to have proved very satisfactory. It is something I know very little about, and I was wondering whether this is not a factor that should be considered.

President Loweth: In regard to corrugated steel pipe; the speaker has no doubt but that comparatively thin metal corrugated pipes, could be made sufficiently strong, but the question would be as to their durability.

The experience of the C. M. & St. P. Ry. with cast iron pipe culverts has been as follows: About fifteen years ago it was discovered that many were breaking; the matter was carefully investigated at the time, some of the causes for the failures were ascertained, and steps taken to remedy them. It was found that one cause was in the use of pipe of too light weight, and since that time heavier pipes have been used. Another cause was that the pipes had not been properly bedded. The secret of the successful use of either cast iron or concrete culvert pipes is that they should be carefully bedded, and no matter how strong they may be, there is great liability of failure if care in this respect is not exercised. Since these defects have been recognized and remedied there have been, so far as the speaker's observation goes, very few cases of broken cast iron pipe culverts. There are many thousand iron pipe culverts, and occasionally some fail, generally cracking longitudinally along the top, bottom, and the sides, and often such failures are not complete and the pipe is continued in service with perfect safety. Of course there are cases where the breaks are such as to cause the removal of the pipes.

The paper presented this evening is gratifying to the speaker, in that it brings out the fact that concrete pipes can be made which will be as strong as cast iron ones; that they are being used by several railroad companies; and that they cost less than cast iron pipes. Then, the point that Mr. Baldwin has brought out, that it will be possible to make concrete pipes on the ground, is another argument in their favor, as frequently the sand or gravel could be gotten at the culvert sites, leaving the cement only to be hauled in, although doubtless it would generally be cheaper to make these in larger lots at some central point. One large advantage in the use of concrete is that in many localities suitable sand, gravel and stone are found in close proximity to the work; much of the concrete work now being done on the Pacific extension of the C. M. & St. P. Ry. is made with gravel obtained at the site, thus resulting in large economies.

Mr. Reichmann: I believe in the past on the lines of the C. M. & St. P. Ry. wooden box culverts were first constructed, and after these had outlived their usefulness cast iron pipes were drawn through these openings. I would like to ask the President if this practice is still followed on the lines of that railway.

President Lowcth: That is the practice of the C. M. & St. P. Ry., old timber box culverts are almost invariably replaced with cast iron pipe, which is laid through the old culvert and earth tamped in between the two. I think that is one of the reasons why the iron pipe culverts have been standing up so well. In new embankments the size of cast iron pipes has been limited to about 36 in.; larger sizes could no doubt be safely used, but much greater care in laying them would be necessary, and, strange as it may seem, this greater care, even in so simple an operation as laying pipes, is very difficult to obtain. Many partial and some complete failures, of otherwise well designed and constructed works, are due to a lack of careful attention to and manipulation of those details of the work executed by common labor. The lack is not so often in skill as in obedient painstaking care, in the most ordinary operations.

Mr. Baldwin: Where you draw your cast iron pipe through the wooden culverts, do you put in a section at a time and then back fill?

President Lowcth: Yes, the old timber culvert is not removed, the iron pipe is put in it a section at a time, and the space between the two well packed with earth. This brings about conditions favorable for the iron pipes as the embankment has already settled, and as the timber culvert gradually rots away the overlying material arches over the pipes so that they never get the full load due to the depth of the embankment over them. The same method could be used, and with the same favorable result, with the use of concrete pipes.

Mr. Baldwin: Would not a higher section be more efficient for the purpose of a culvert?

Professor Talbot: The bending moment would be nearly the same since the horizontal diameter is not to be changed, and the effect of the horizontal pressure is relatively less.

Mr. Baldridge, M.W.S.E.: In Fig. 12b, it seems to me, a tendency is shown for the reinforcing bars to pull out of the concrete at the top and bottom of the pipe. Does that not indicate a necessity for imbedding them more deeply into the concrete?

Professor Talbot: I think that action is due to a vertical tension, so to speak. If the rods were placed a little further in, there would be no greater resistance to this stress, and of course this change would weaken the resisting moment of the pipe.

Mr. Reichmann: I would ask Mr. Cartlidge if he makes his reinforced concrete pipe with the flat bottom as shown on the screen by Prof. Talbot.

Mr. Cartlidge: No.

Mr. Reichmann: I would also ask Mr. Cartlidge whether he has ever tried any rectangular sections of pipe?

Mr. Cartlidge: No, I have never used a rectangular section of pipe.

Mr. T. L. D. Hadwen, M.W.S.E.: I would ask Mr. Cartlidge what

is the maximum diameter of the pipe he has used so far, and the usual lengths?

Mr. Cartlidge: The diameter of the largest pipe we have made was 48 in. So far we have had no occasion to use any larger size, although we have contemplated making forms and building a 60 in. pipe. The length is approximately 8 ft. to allow placing on cars.

Mr. B. J. Ashley, M.W.S.E.: There seems to be two elements that have not entered into the discussion this evening as extensively as I had expected,—namely, the relation of the thickness of the pipe to its diameter, and the matter of mixture. It seems to me that some very interesting data could be brought forth by experiments in thickness; for instance, comparing the thickness of the shell of pipe one foot in diameter with that of a pipe four feet in diameter; there certainly in a relation there that enters very materially into the strength of the pipe. Then, one must not lose sight of "mixture," which is also an element of supreme importance, and while I am not very much interested in a business way in this class of work, I seem to see that there might be some tables or charts worked out that would show established rules of practice, by which charts or tables, the engineering fraternity may be guided when designing concrete conduits for specific purposes, and whereby the necessity of having to continually calculate these results would be done away with.

Mr. Cartlidge: It is extremely important, in designing pipe to use on the road, to take into account the weight which must be handled, and in designing the 48 in. pipe, which is the largest pipe we make, we made it somewhat less than the weight of the section of 48 in. cast iron pipe, believing that the latter was rather heavier and more expensive to handle than we wished to use. We make our 48 in. reinforced concrete pipe about 4 in. thick. If we were to increase the thickness we could undoubtedly get a better pipe, but we think the 48 in. pipe, as we make it, is strong enough for our use, and we have gotten it as light as we can.

With reference to the 12 in. pipe, I hardly think it is best to make a reinforced concrete pipe of a diameter less than 24 in. to compare in cost with cast iron pipe. It is very likely that plain concrete pipe can be made amply strong, with a diameter less than 2 ft., which will cost less. We have not tried it, however.

Mr. R. H. Kuss, M.W.S.E. (by letter): Pure speculation induces the belief that the shape which concrete culvert pipe will take ultimately will be elliptical and were it not for the fact that the casting of iron in cylindrical shapes other than circular is attended with many difficulties not encountered in circular castings, we might expect a similar result even with the use of this latter material.

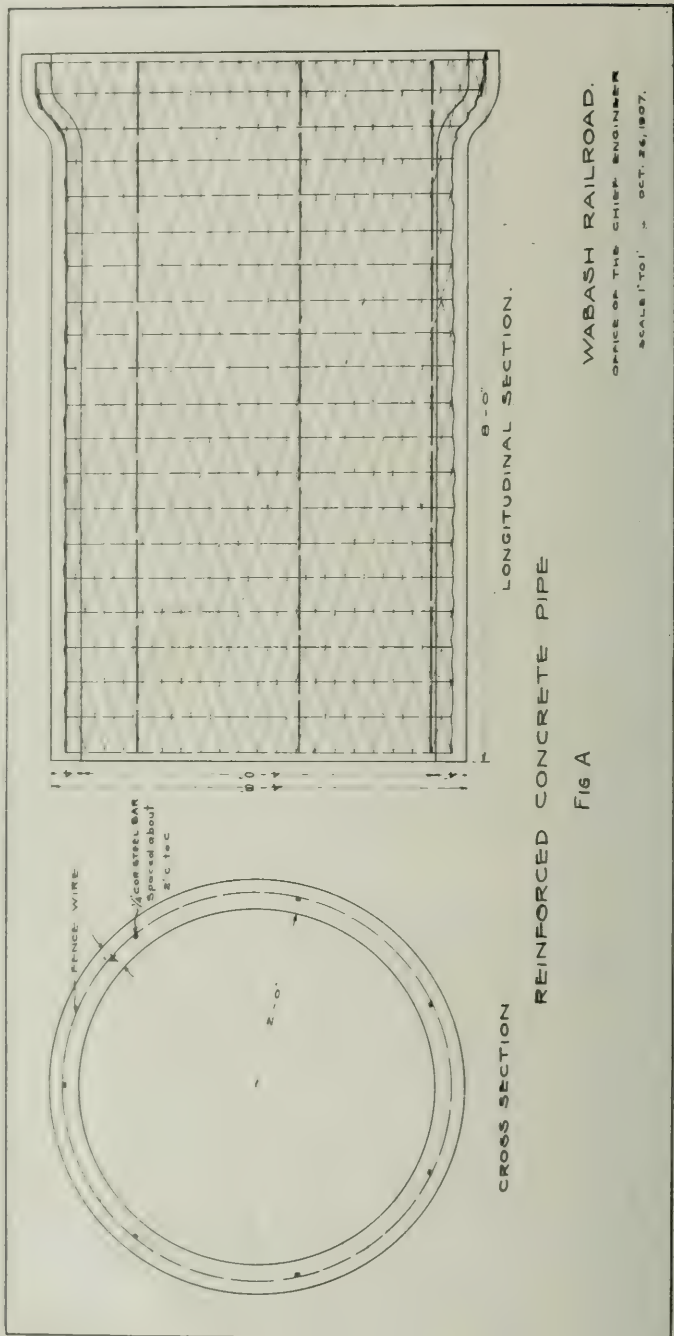
The advantages are really two-fold in character; first, the greater resistance to failure, on account of stresses due to loading, peculiar to the uses to which the pipe is put; and second, the greater ease in bedding the pipe satisfactorily. The foregoing are primarily dependent upon the fact that when culvert pipe is placed in a trench, the

greater load is usually vertical and the pressure upon the sides of the pipe, which assists the pipe in resisting this vertical load, is somewhat smaller than the vertical load, the difference between the two, speaking in general terms, being made up by the resistance of the material of the pipe itself.

Considered as an elliptical cylinder and subject to a concentrated load directed along the major axis of the ellipse which is held in equilibrium by an equal and opposite force applied on the opposite sides of the ellipse, the elliptical shape possesses greater resisting powers than a circular cylinder, similarly treated of the same area of section and of the same thickness and kind of material. Analagous cases are those of chain links (without studs) and crane hooks, the difference being merely the sense in which the forces are applied. The advantages of the elliptical shape are very marked in the cases cited and at least hold up to the deductions arrived at mathematically within the elastic limits of the materials employed. When the load becomes distributed uniformly over the surface of the horizontal section, the problem becomes more complicated in its analysis though the advantages for the elliptical shape become no less marked, provided the directions of the several forces remain parallel to the major axis of the ellipse. It is especially when there is a combined distributed vertical load, together with a horizontal load distributed over the sides as approximated in the actual use of culvert pipe carefully placed, that the advantages of the elliptical section become apparent if the major axis is maintained vertical. In this case the preponderance of the vertical over the horizontal forces becomes less great as the length of the major axis to that of the minor axis becomes greater, thereby reducing the maximum bending moments and causing the stress in the material to become more nearly uniformly distributed over the section of the material.

One of the disadvantages in the use of circular pipes as compared with elliptical ones is that it is somewhat more difficult to tamp the filling of the earth under the lower half of the pipe. The elliptical shape does not require as much care in bringing about the same condition of security as does the round one. Those who have used culvert pipe seem to agree that it is one of the most difficult things to obtain a uniform bed for the pipe to lie on. This is not only true in the matter of obtaining solid earth work around the lower half of the pipe itself, but it is altogether likely that each section of pipe is not supported uniformly along the bottom. The elliptical shape is better adapted to carry a vertical load for the same reasons that a beam with its larger dimension vertical is better adapted to support weight loading, than a beam of circular section containing the same thickness of materials and the same area of section.

Mr. L. Bush, M.W.S.E. (by letter): As to my experience with cast iron pipe for railroad culverts, I will say that I do not recall a case where the cast iron pipe has been broken under traffic, and in my opinion there is but very little danger of breaking cast iron pipe if it


LONGITUDINAL SECTION.
8-0"
CROSS SECTION
FENCE WIRE
1/4 COR STEEL BAR Spaced about 2' c to c
REINFORCED CONCRETE PIPE
FIG A
WABASH RAILROAD.
OFFICE OF THE CHIEF ENGINEER
OCT. 26, 1907.

is properly bedded when put in place. I put in considerable pipe on the Iowa division of the C. & N. W. R. R. during the year that I was on that Division and we used care in making a trench for the pipe and also care in tamping good gravel or other solid material around the pipe. It is necessary and important in placing cast iron pipe that a sufficient covering be placed over it and with this done and proper bedding, I believe there will be very little breakage. I have seen cast iron pipe cracked in handling from cars when pipe was rolled or dumped from cars instead of using a derrick for unloading.

Mr. A. O. Cunningham, Chf. Engr., Wabash R. R. (by letter): Prof. Talbot's paper on Reinforced Concrete and Cast Iron Culvert Pipe is timely, interesting and valuable, and should prove beneficial in the designing of reinforced concrete pipe. A great many of the railroads are using concrete pipe instead of cast iron pipe on account of the fact that the former is cheaper than the latter. I have thought it might be interesting to present some designs which have been used on the Wabash, and others which it is contemplated to use. The Wabash R. R. at the present time is using a pipe 8 ft. in length, varying in diameter 2 ft. and 4 ft. From the drawing attached, Fig. A, it will be seen that this pipe consists of longitudinal corrugated bars spaced about 2 ft. on centers, around which is wrapped wire fencing; this reinforcing being surrounded by a ring of concrete 4 inches in thickness, and being centrally located within the concrete ring. The great trouble with the manufacture of pipes of this length has been due to the difficulty of placing the reinforcing properly and tamping the concrete around it in a pipe of such great length. The forms for pipe of this length are expensive, and the cost of labor is high from the fact that a platform 8 ft. high has to be built on which the men have to stand in order to fill the concrete forms and tamp the concrete properly. Also on account of the weight of the forms and the pipes, derricks have to be used in handling. On account of the difficulty in tamping, imperfections are bound to appear in certain portions of the pipe, which show up sometimes in transportation, and at other times while being unloaded at the site for which they are intended. In most cases, it is the bell that suffers. Our experience has been that after the pipes are in place no trouble is found with them due to the superimposed loads. In order to overcome the difficulties previously stated in manufacturing long pipes, the writer suggests that they be made in shorter lengths, and with the bell of a different design.

Drawings are presented showing 2 ft., 3 ft., and 4 ft. diameter pipes, made in lengths of 3 ft. 4 in., shown in Figs. B, C and D.

Plan is also presented of a form for 4 ft. diameter concrete pipe, the general length of which could be used in making forms for 2 ft. and 3 ft. diameter pipes. See Fig. E. These forms are of such weight that they can be readily handled by two men. They can be filled from the ground without necessitating the building of a

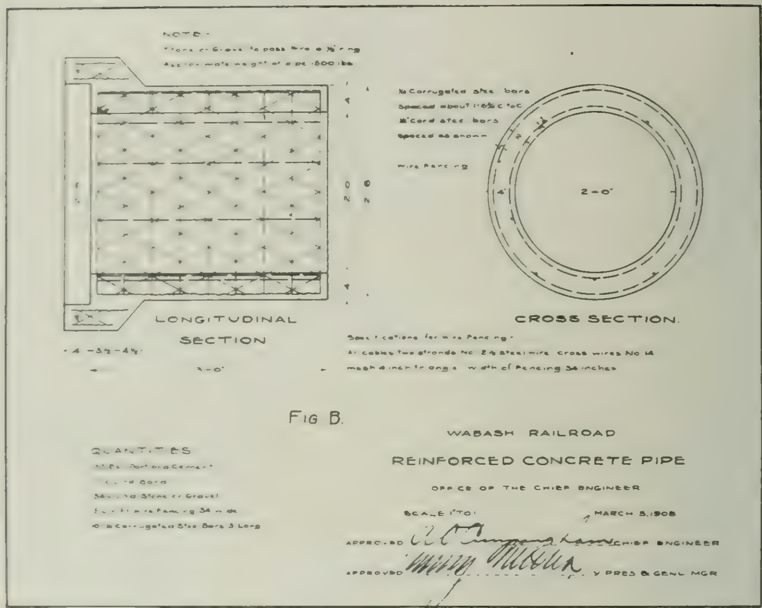

LONGITUDINAL SECTION
CROSS SECTION.
2-0"
WABASH RAILROAD
REINFORCED CONCRETE PIPE
OFFICE OF THE CHIEF ENGINEER
MARCH 5, 1908
CHIEF ENGINEER
V PRES & GENL MGR
QUANTITIES

FIG B.

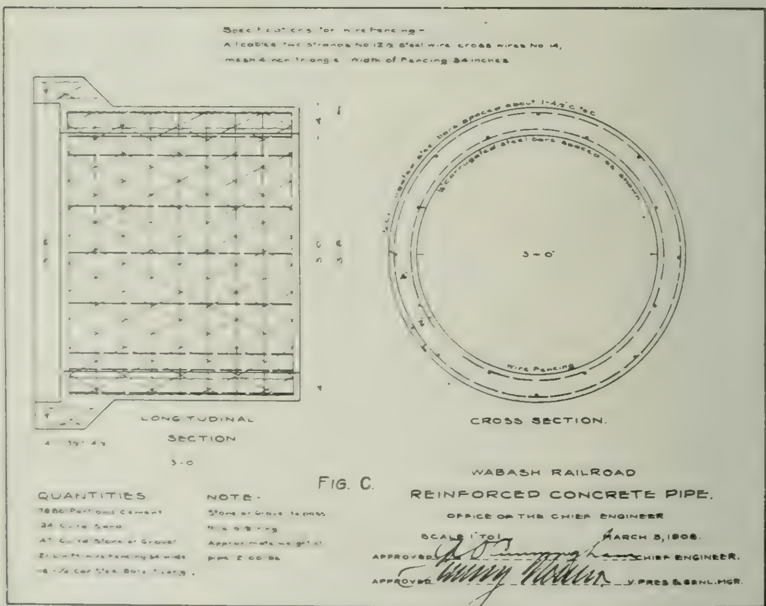

LONGITUDINAL SECTION
CROSS SECTION.
3-0"
WABASH RAILROAD
REINFORCED CONCRETE PIPE.
OFFICE OF THE CHIEF ENGINEER
MARCH 5, 1908.
APPROVED
CHIEF ENGINEER.
V. PRES & GENL. MGR.
QUANTITIES
NOTE:
Wire Fencing

FIG. C.

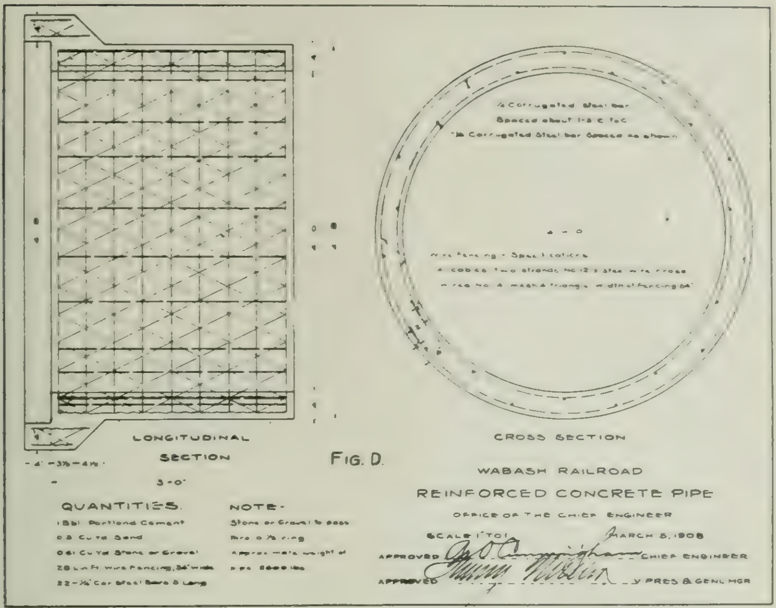


FIG. D.

platform and the pipe can be rolled around and handled without a derrick. Of course, it would be advisable to use a derrick in loading the pipe on cars. The pipe are of such shape that they can be set on end on a car; thus requiring no blocking to keep them in place, which means there will be less liability of damage in transportation.

The advantages of these short lengths of pipe are:

1st. In their manufacture, since they can be made a great deal more cheaply than the long pipe.

2nd. Less damage during transportation and loading and unloading.

3rd. They can be handled easier at the site for which they are intended.

4th. They will bed themselves better under the superimposed load, and settlements will be taken up by the joints.

Mr. E. W. Grant, Asst. Engr., A. T. & S. F. Ry., Topeka, Kas. (by letter): Until within a few years, nearly all of the small openings required for drainage on the important sections of the railroad with which I have been connected for some time, have been cast-iron pipes. Vitrified pipes were discarded many years since except upon one line recently constructed, where quite a large number of them of small size were used. However, several of these were encased in concrete. Recently, small single or double arches, or in some cases, box culverts of plain concrete have been built instead of using cast-iron pipes; but so far, reinforced concrete pipes have not been adopted upon any of the lines with which I am familiar.

While the apparent cheapness of reinforced concrete pipes as compared with cast-iron pipes appeals to one, the many difficulties in the way of constructing uniformly good pipes of concrete, against the known lasting qualities of cast-iron, tend to neutralize this seeming advantage.

For small openings requiring very little concrete, the difficulty in getting the combination of good material, proper proportioning of the ingredients, thorough mixing of the concrete, and proper placing of the reinforcement—as compared with the ease with which cast-iron pipes can be placed—give the latter great advantage. The personal factor in making reinforced concrete is very large, while for cast-iron pipe it is nothing except in placing, and it is equally great in this respect for reinforced concrete pipe. Cast-iron pipes, however, are not altogether satisfactory, principally on account of this personal factor. Many of them break, either from careless handling, or by not being properly bedded or covered; some failures may occur because the pipes are of inferior quality, or are not of uniform thickness. Some 36-in. pipes which I recently measured were found to vary 19% in thickness in the same piece, this ranging from thirteen-sixteenths of an inch to one inch.

While instructions have been often given for the placing and covering of pipes, fixed rules have not been uniformly nor rigidly followed. However, pipes have usually been put upon firm ground and the beds were prepared so as to conform to grades given by the engineers, an allowance being made for the difference in the settlement of the pipes in the center and at the ends. It has not been the practice to excavate deeper in earth for the bell ends than for other parts of the pipes, so that these ends must be forced down sufficiently to distribute the load along the pipes. Usually in refilling, the compacting of the material at the sides by teams is supplemented by tamping, and if there is more than one line of pipe they are so placed that this also is done between them. It is, however, very difficult to get such work properly performed, partly from lack of constant supervision or because of the inexperience or carelessness of the inspectors or the indifference of the workmen. As a consequence many pipes have broken down, or at least cracked along the sides when by care in bedding this could have been prevented. Instructions have recently been given to insert vertical posts temporarily at all joints and also midway between them in all pieces twelve feet long. These are to be allowed to remain until the new embankments have completely settled. In the case of some large pipes (48 in.) which have failed under high embankments, cross-breaks as well as longitudinal cracks along the sides have occurred and pieces of the pipes have fallen down. In one such instance two lines of 48-in. pipe were under an embankment 53 ft. high; at another point four lines of 48 in. pipe were under a 62 ft. embankment; and at another place two such pipes were partially crushed under a 51 ft. embankment. Other instances of failures might be mentioned. In all of these cases, the

material placed around the pipes was of a clayey character. The insertion of temporary posts in these pipes might have prevented the failures, or the bell ends may have helped to produce them. It is evident that there would be great economy in dispensing with bell ends as, from my observation, they amount to about 10% of the total weight of 12 ft. lengths. I think wooden saddles made from old bridge stringers or other suitable second-hand timbers could be used to keep the pipes in place until the earth settled firmly around them. Strips of sheet-iron could be placed over the joints to prevent the earth falling in. At any rate, it should not be difficult to keep the pipes in position without bell ends. The entrance of small quantities of material through the joints or the slight flow of water through them and along the outside of the pipes could do but little harm especially with the usual head wall to prevent large, outside channels. The choice of openings, that is, whether they should be of iron, reinforced concrete or plain concrete, will depend upon the existing organization and equipment for doing the required work.

Mr. Job Tuthill, Bridge Engineer, Pere Marquette R. R. (by letter): In addition to the valuable information given by the tests, Prof. Talbot has developed formulas applicable to the designing of reinforced concrete pipes, which promise to become an economical and a desirable substitute for the larger sizes of cast-iron pipes and more expensive forms of concrete or masonry construction for small culverts and waterways for railroad use. The tests show the critical load for reinforced concrete to be four-tenths of the load causing the first crack in cast-iron, indicating that the former can be considered as having at least four-tenths the strength of cast-iron pipe, which would seem ample for most railroad culverts where pipe is suitable. Similar tests of vitrified pipes would also be of value for comparison.

An experience extending over a number of years in the use of vitrified clay pipe from 12 in. to 36 in. diameter, for culverts under railroad embankments, has shown that out of five hundred of ordinary sewer pipe, one in every six has failed. The double strength vitrified pipe, made especially for culvert use, has shown much better results,—in seven hundred and thirty of these the proportion of failures has been one in thirty. The life of these pipe has been from two to twenty or more years,—some of the oldest being still in perfect condition. These failures have not seemed to follow any general rule, but have occurred under embankments of all heights from three feet to twenty,—the larger proportion under the lighter embankments. More have failed that are dry or nearly so for the greater part of the year, especially during the winter, than those that are continually full or nearly so of water,—due possibly to the earth freezing above and below them. A larger proportion of failures have occurred where the pipes were placed when the embankments were constructed than where pipes were put under old embankments to replace timber culverts. These last, however, seem to show an increasing proportion of failures during the past three or four

years, indicating that some protection was perhaps afforded for a time by the old timber, or that these embankments are still settling and compacting under the heavier rolling stock of later years.

The only failures of cast-iron pipe that have come under the writer's observation have been one of six feet and one of five feet diameter under new embankments made by filling trestles and occurred soon after the fills were made. These fills were forty-five or fifty feet high, made by dumping from small cars from each side of the trestle for half of their height and from the top of the rest. The failure was by shearing in a plane nearly through the horizontal diameters. Especial care was taken to bed these properly.

The tests also emphasize the importance of carefully bedding the pipe and thoroughly tamping the filling around it. To the lack of care in this particular can be attributed a large proportion of the failures of sewer and culvert pipe.

Mr. Chas. S. Churchill, Chf. Engr. N. & W. Ry. (by letter): We use, to a certain extent, cast-iron pipe for culverts. Owing, however, to variations in weight of cast-iron pipe in comparison with shipping bills, we have recently found it advisable to purchase all pipes under a specification, and a specification is now in print for our use hereafter. I should add that we have not had any trouble with the breakage of cast-iron culverts in our roadbed.

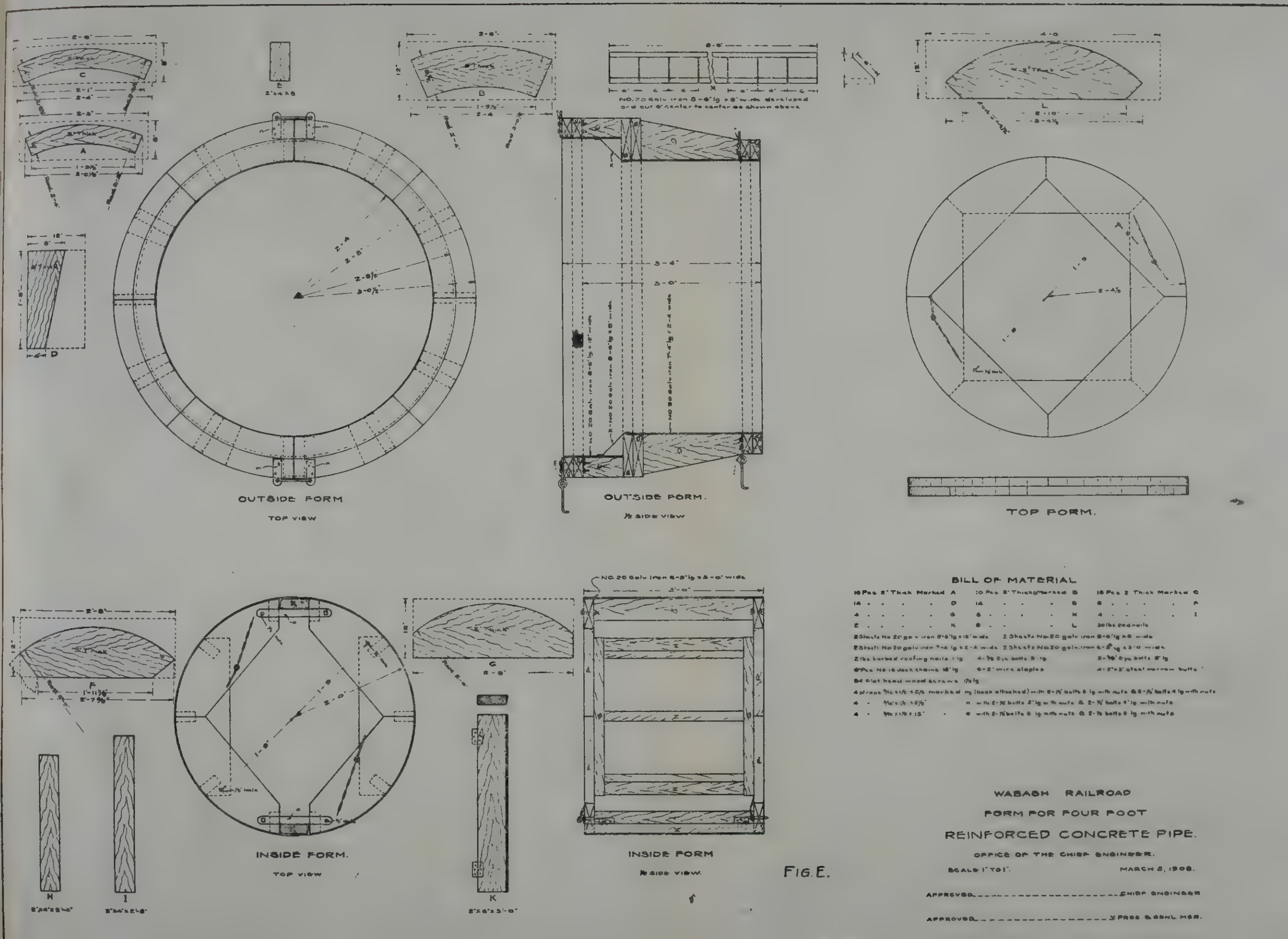
SPECIFICATIONS FOR CAST IRON PIPE

STANDARD THICKNESSES AND WEIGHTS OF CAST IRON PIPE

Nominal Inside Diam. inches	Thickness inch.	Class A 100-foot Head 43 Pounds Pressure Weight Per Foot	Length
4	.42	20.0	240
6	.44	30.8	370
8	.46	42.9	515
10	.50	57.1	685
12	.54	72.5	870
14	.57	89.6	1,075
16	.60	108.3	1,300
18	.64	129.2	1,550
20	.67	150.0	1,800
24	.76	204.2	2,450
30	.88	291.7	3,500
36	.99	391.7	4.700
42	1.10	512.5	6,150
48	1.26	866.7	8,000
54	1.35	800.0	9,600
60	1.39	916.7	11,000

The above weights are for 12 feet laying lengths and standard sockets; proportionate allowance to be made for any variation therefrom.

No pipe shall be accepted the weight of which shall be less than the standard weight by more than five per cent. for pipes 16 inches or less in diameter, and four per cent. for pipes more than 16 inches in diameter, and no excess above the standard weight of more than these given percentages for the several sizes shall be paid for. The total weight to be paid for on each requisition shall not exceed for each size and class of pipe received the sum of the standard weights of the same number of pieces of the given size and class by more than two per cent.



OUTSIDE FORM
TOP VIEW
OUTSIDE FORM.
½ SIDE VIEW
TOP FORM.
INSIDE FORM.
TOP VIEW
INSIDE FORM
½ SIDE VIEW.
BILL OF MATERIAL
WABASH RAILROAD
FORM FOR FOUR FOOT
REINFORCED CONCRETE PIPE.
OFFICE OF THE CHIEF ENGINEER.
SCALE 1" TO 1'.
MARCH 5, 1908.
APPROVED ____________ CHIEF ENGINEER
APPROVED ____________ V. PRES. & GENL. MGR.

FIG. E.

CULVERT PIPE.

Culvert pipe shall consist of such second quality pipes, not cracked, as would be subject to rejection under the two aforementioned specifications. The weight per length desired is not less than class "A" of list given above, and in no case shall the cost per length at reduced price exceed the cost of Class "A" pipe when perfect, at full price.

They shall be able to withstand pressure from the outside, though not necessarily from the inside. They may be cut to remove cracked parts to any length not less than six feet, but must have hub on one end. They must not have imperfections of such a nature that the spigots will not enter the hubs, but no space for lead is herein specified as to its thickness, nor in any special design of spigot or hub. No less thickness than that specified for Class "A" pipe shall extend for a width or length of more than 12 inches, or more than half way round the pipe, and the thickness at such defects shall not be less than 70 per cent. of that prescribed in Class "A" pipe of same diameter. Culvert pipe shall be coated as specified for pressure pipe in the two beforementioned specifications; they shall be subject to inspection under the specifications here written, and to legalized weighing.

OFFICE OF CHIEF ENGINEER, ROANOKE, VA.
MARCH, 1908.

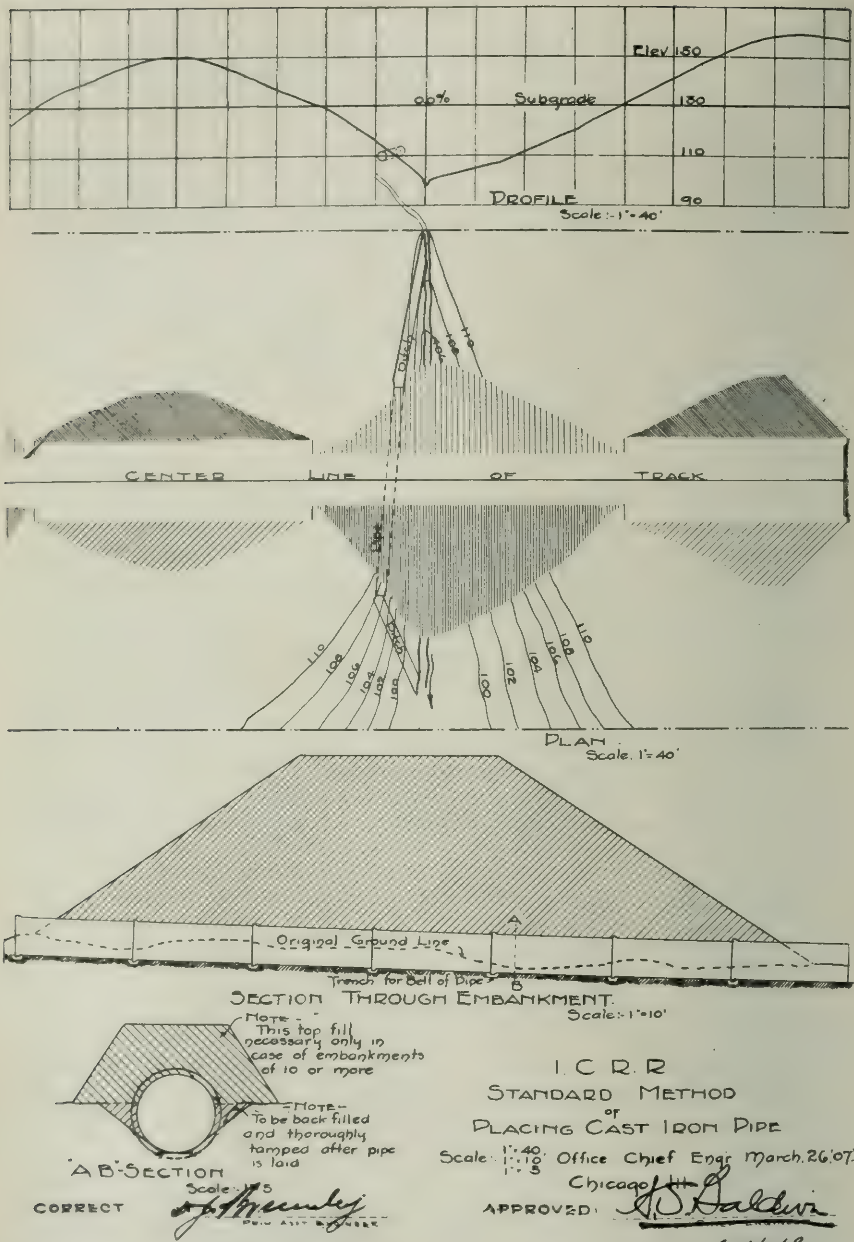
CLOSURE.

Prof. Talbot: The relation of the thickness to the diameter of the pipe has been brought up. If we consider the total load to be proportional to the diameter of the culvert, it will be found that the bending moment developed in the pipe is proportional to the square of the diameter; and since for a cast-iron pipe (neglecting the element of thickness usually added to provide against the eccentricity of core in the casting) the resisting moment is proportional to the square of the thickness, it follows that for common unit loads the thickness of the pipe would need to be directly proportional to the diameter. This is quite in keeping with usual practice. Similarly, in reinforced concrete pipe, if the amount of reinforcement is kept a constant percentage of the area of effective cross section, the thickness of the pipe, or better the distance from the center of the steel to the face of the concrete, may properly be made proportional to the diameter.

The writer is pleased to see the general appreciation of the value of carefully bedding culvert pipe in place and of filling and tamping over the pipe. Whether the bell may be well dispensed with is a question worthy of consideration. What the actual load which comes upon a culvert pipe in an embankment amounts to, is a very uncertain question. Evidently as the embankment becomes older the pressure on the pipe may decrease. The further collection of data of failures under known conditions will add to our knowledge, and it is possible that further experiments may be of service.

ADDENDUM.

The practice of the Illinois Central R. R. Co. in the matter of Cast Iron Pipe Culverts is shown in the following "Specifications for Placing Cast Iron Pipe." The illustration makes the matter clear, and the Chief Engineer, Mr. A. S. Baldwin, M.W.S.E., writes that they find these instructions "to be of material assistance."



Elev 150
0.0%
Subgrade
130
110
90
Profile
Scale:-1"=40'
Ditch
Center Line of Track
Pipe
110
108
106
104
102
100
Plan
Scale. 1"=40'
A
Original Ground Line
Trench for Bell of Pipe
B
Section Through Embankment.
Scale:-1"=10'
Note -
This top fill necessary only in case of embankments of 10 or more
Note -
To be back filled and thoroughly tamped after pipe is laid
"A B" Section
Scale: 1"=5
Correct
Approved
I. C. R. R.
Standard Method of Placing Cast Iron Pipe
Scale 1"=40, 1"=10, 1"=5 Office Chief Engr March. 26. '07.
Chicago, Ill.
4-H-69

SPECIFICATIONS FOR PLACING CAST IRON PIPE.

Cast-Iron Pipe shall be placed at such points as the Engineer directs. It shall be placed true to line and at right angles to the center of the track where practicable, with the bell ends up stream, and shall have such uniform grade in the direction of the flow as shall be determined by the physical conditions at the point where laid and as approved by the Engineer. No portion of any pipe drain and no joint of pipe in any drain shall be blocked or shimmed or held in position by filling under it or by any other artificial means. A bed of uniform grade shall be prepared to receive the pipe by excavating or cutting off the uneven places in the earth or other material where the pipe is to be laid, and recesses must be cut to receive the bell ends so that each joint of the pipe shall have a firm bearing throughout its entire length upon the solid earth.

In case rock is found where it is necessary to lay pipe, the bed shall be prepared for the receipt of the pipe as described herein above, except that the excavation shall be carried uniformly three to six inches lower than the grade of the pipe and backed, filled and tamped with spalls to form an even bearing and cushion for the pipe.

Each joint of pipe shall be fitted into the next adjacent pipe carefully and so that the spigot end of each pipe shall be inserted in the bell end of the pipe adjacent as far as it will go.

After the pipes are in place the trenches prepared to receive them shall be backfilled and tamped to be level with the original surface of the ground.

Where pipes are laid under rock fills ten feet or more in height, built by dumping rocks from a trestle, the pipes shall be covered to a depth of three feet with earth or other suitable material, carefully placed before dumping against them will be permitted.

Where practicable the pipe drains shall not be placed at the lowest point of the drainage. They shall be so placed that the upstream end will provide suitable drainage to the property adjoining the right of way and secure a fall of one-tenth of one foot in twenty feet from the right of way line to the inlet end of the pipe.

Provision must be made for ample inlets and ample outlets to pipe drains within the limits of the Railroad Company's property.

Special care must be exercised in unloading and handling cast-iron pipe. Any cast-iron pipe broken in unloading, hauling or placing through the negligence of the Contractor or his employees shall be paid for by the Contractor.

ALTERNATORS IN PARALLEL

By Morgan Brooks, M.W.S.E.

Presented March 11, 1908.

The successful operation of alternators in parallel depends upon a combination of favoring circumstances more or less under control. A consideration of the influence and relative importance of some of these circumstances is the object of this paper. Synchronous motors or converters operated by generators from a distance are in fact in parallel with these generators, and conditions of such motor operation will be included.

When two similar shunt-wound direct current machines are running in parallel, and the driving power of one machine fails, that machine tends to slow down as would be expected. As soon, however, as its induced electro-motive force is thereby decreased enough to permit current to flow back through it from the other generator it becomes a motor, and continues to run without much apparent change. In a somewhat similar way in the case of two alternators in parallel, if the driving power of one machine fails it tends to slow down, but as soon as its vector position with reference to the generator falls behind a mere fraction of a cycle, current can flow backward making it a motor even without any reduction whatever of its induced electro-motive force. It then continues to run as a motor and at synchronous speed. The tendency to slow down in this case results immediately in a lagging position, but the machine is held in step, dragged along by the current it receives. The actual change in vector position is often very slight, a matter say of 2 degrees electrical, that is, only ½ deg. actual in an 8-pole machine. The change is so slight it is hard to realize that such change marks the difference between generator and motor action of the same machine.

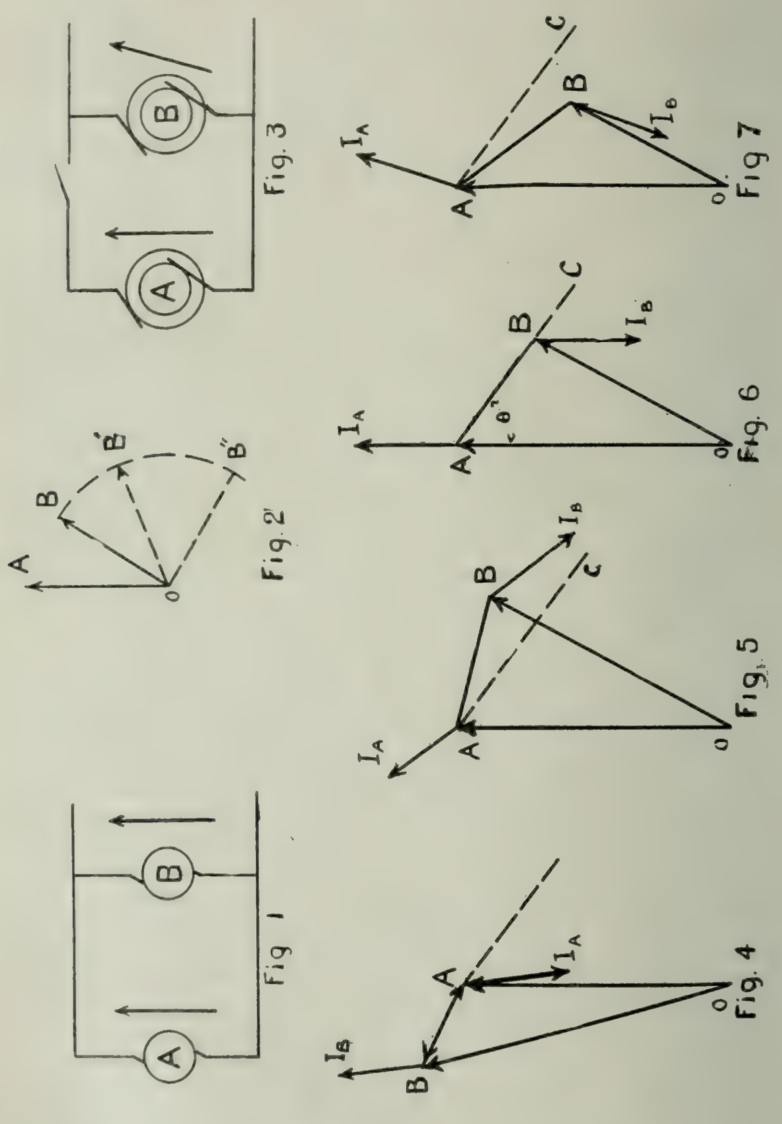
For the interpretation of these facts, as well as the presentation of other interesting features, the chart shown in Fig. 12 has been prepared. This chart is derived as follows: Fig. 1 represents two direct current machines, A and B, the vectors representing induced electromotive forces. If A is generator and B is motor, current will flow with vector A and against vector B in the closed circuit shown. Fig 3 shows two alternating current machines, A and B, not connected in circuit. The vectors may have any possible relation, as shown more clearly in Fig. 2, which represents the relative positions of any two alternators, A and B not connected together.

Both vectors are assumed to rotate counter-clockwise at approximately synchronous speed, vector B gaining (or losing) with respect to A. If we can only catch a glimpse of the vectors at the moment when A is in the vertical position shown, we then have just the condition shown by the synchroscope with its revolving hand, and the form of diagram is justified by the appearance of the synchroscope.

Indeed if we represent the vectors in opposition as shown in some text books how can three or four machines in parallel be represented? If now we assume that a paralleling switch is closed when the vectors are nearly in phase as represented in Fig. 4 the vector-difference voltage, AB properly E, the e. m. f. of the local circuit, acts to drive current through the impedance of the local circuit. Whether this vector-difference E, should be indicated with its direction toward B or toward A depends on the point of view. With regard to A, its positive direction is BA; while with reference to B, its positive direction is AB. Fig. 4, shows arrows at both ends to indicate this. Now BA drives a current shown at I_A lagging by a definite angle θ dependent on the impedance of the local circuit. Cosine θ is the proper power factor of the local circuit of the two machines. This current is nearly in phase with OA, the e. m. f. of machine A. This indicates generator action, and there is a load upon machine A due to this circulating current. Viewed from the machine B, the active e. m. f. AB furnishes the same current, represented this time as I_B lagging θ deg. behind AB, which current is nearly in opposition to vector OB, showing that machine B is momentarily a motor, whose speed will be accelerated. That is, the generator action on A and the motor action on B both conspire to bring the machines together in vector position. In passing through identical phase position at equal excitation the action passes through zero, meaning that no synchronizing action holds the machines together, but that such action operates as soon as the machines separate to prevent their falling apart. It is a sort of elastic coupling whose force increases with angular separation. The force action becomes enormous at small vector angles, and synchronous machines cannot be pulled out of step without very great strain.

It will be noticed that since the current vector always lags by angle θ deg. behind the resultant e. m. f. E. The terminal B, of machine vector OB must lie along a line AC Fig 6, making angle θ with AO to produce a circulating current in phase with OA. In synchronous motor operation, proper excitation to produce this result is known as "normal" excitation, and gives what is known as unity power factor. Any greater excitation will produce a current which leads vector *OA*, Fig. 5, any less excitation a current which lags behind OA, Fig. 7. When the current leads or lags, the power factor is properly denoted as Cos. a, and should not be confused with Cos. θ the legitimate power factor of the local circuit, which tells the current relation to resultant e. m. f. E, the vector-difference between OA and OB. The difficulty in recognizing this Cos. θ power factor lies in the fact that AB has no visible existence immediately the switch is closed between the machines in parallel operation, and as between generator and its motor in a distant station, the e. m. f. is difficult to measure. Nevertheless a vector difference may exist, even if not accompanied by a voltage difference that can be measured. That this vector difference is a fact is evident from a consideration of the oscillating vector

positions due to hunting, causing surges of current to flow forward and back between the machines, rapidly changing their function from generator to motor and back again. The diagram, Fig. 4, is thus a representation of the relation between voltages as would exist



at the moment of switch closing, or of switch opening if that were done.

From the power equations of the machines A and B—OA x I x Cos a and OB x I x Cos b (where angles a and b indicate the relation of current to vectors OA and OB) the chart, Fig. 12 has been drawn by a method explained in detail in a paper "Interaction of Synchronous Machines" proceedings A. I. E. E. June 25, 1907. The

Fig. 8

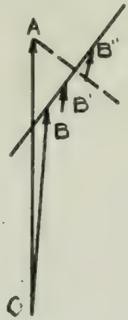


Fig 9

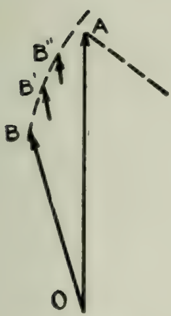


Fig. 10

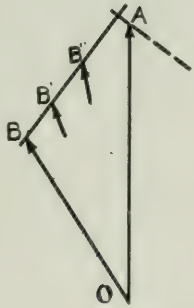


Fig. 11

heavy circle OAV is the locus of B of vector OB where there is no transfer of power to machine B. For any postion of B in this circle a current lagging θ deg. behind AB will necessarily be at 90 deg. from OB, and hence cos b will equal O. The current sent out by the generator A is all consumed in I^2R losses. For positions of B within the circle, such as B, power is received by machine B in proportion to its distances from the circumference, the maximum power occurring when the vector falls at C the center at an efficiency of 50%. Positions within the upper part of the circle above diameter OCV are stable running positions, below that diameter unstable, since

here the slightest increase in load tending to make the machine B fall behind drives it into a position of less power intake.

Positions of vector OB without the reference circle show a reversed function of B, which then becomes a generator with respect to A as motor, although there is the restricted space lying between the reference circle and its tangent at A, where both machines are generators, machine A not changing from generator to motor until B takes a position to the left of the tangent through point A. Where it is desired to consider two or more machines as motors, points within the

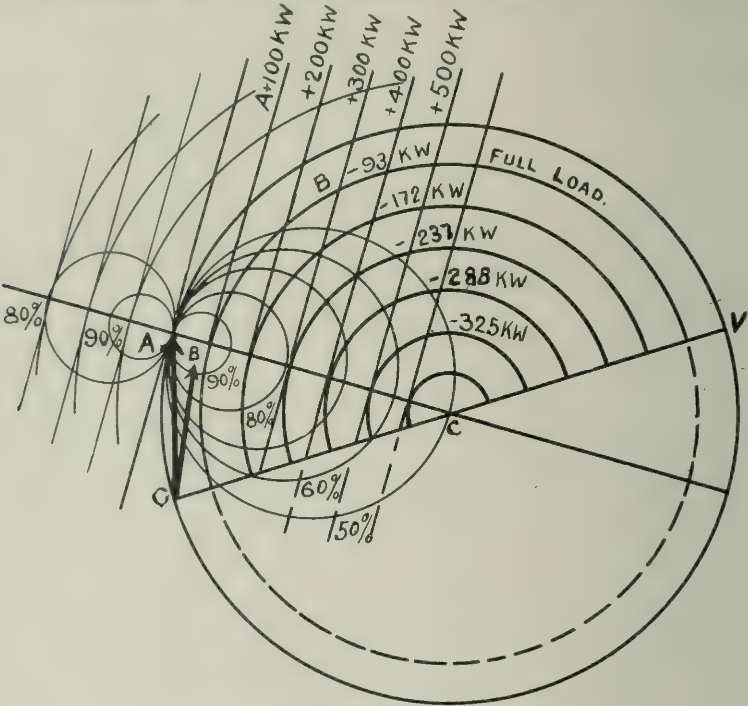


Figure 12

circle are required for vectors, vector OA representing the single generator or the combined result of all generators. Where it is desired to consider two or more generators in parallel, points without the reference circle show such generators, where OA represents the entire load.

The circle within and without the reference circle marked "full-load" is estimated, and is to be taken as illustrative rather than as absolute. The angle θ taken at 74 deg. in Fig. 12, is intended to illustrate normal condition of parallel operation proper. This angle is often given as 90 deg. in popular texts, but cannot greatly exceed 75 deg. in actual practice and comes down to 60 deg. probably on ordinary transmission lines.

The chart is calculated for assumed values of resistance and reactance as follows:

R, resistance of alternator or motor, $=0.7$ ohms

X, reactance of alternator or motor, $=2.4$ ohms

Z, impedance of alternator or motor, $=2.5$ ohms

When power transmission is considered, the constants r and x of the circuit are included. R and X are not precise constants, but are assumed at such values as give reasonably simple calculations. Since the lag angle of the current, I, behind the resultant electro-motive force, E, is determined by these constants, we find that tan θ $X \div R = 3.43$ showing $\theta = 74$ deg.

Similar charts could be readily made for any given conditions, either measured or assumed. The results do not include all the conditions of the problem, which is exceedingly complex, and yet they will serve to indicate what may be expected under operating conditions with some certainty.

Vector A is taken as fixed, meaning that the terminal voltage of this machine is constant at 1,000 volts. Vector B is however viewed as the induced voltage of that machine. Any variation of voltage is considered as existing entirely in the B vectors. Positions of B within the reference circle are motor positions, and loci for definite loads are circles concentric with the reference circle, whose circumference is the locus for zero power delivered. The locus marked full-load is basd on 100 amperes of current at maximum efficiency; with over or under-excitation of the motor full-load will require more than 100 amperes. With transmission line included, full-load again means 100 amperes of current at maximum efficiency for this case, which is necessarily less than under local circuit conditions.

The use of the diagram lies in observing what change as to power intake of one machine or of the other is caused by a given change of excitation, of vector position or of load.

Fig. 8 shows constant power of motor B under varying excitation, shown by different lengths OB, OB′, OB″.

Fig. 9 shows constant power drawn from generator A, although excitation and power of B vary.

Fig. 10 is the reverse of Fig. 8, and shows constant generator action of machine B under varying excitation.

Fig. 11, the reverse of Fig. 9, shows constant power of A now a motor, derived from B, a generator, whose output and excitation vary.

The circles, Fig. 12, marked 60 per cent, 70 per cent, 80 per cent, 90 per cent. efficiency are interesting, loci of B, showing that in general a motor may give out the same power at the same efficiency but at different excitations. When, however, the excitation for a given load is "normal," as previously defined, the efficiency is a maximum for that load. It is observed that the use of a converter "over-excited" to balance other inductive load is necessarily at a lower efficiency, and since the power and efficiency loci separate at a rapidly

increasing rate with departure from the line AC of normal excitation, and great departure from that line is at considerable loss of efficiency. Taking all conditions into consideration it is probably best not to attempt to raise the power factor to complete unity where induction motors are used on same transmission line. The highest combined efficiency will generally be obtained by raising the power factor to perhaps 95%, retaining a fairly good efficiency for the synchronous motor not too much over-excited.

In order to operate alternators in parallel, it is first necessary to synchronize the machines. This process, once difficult, has been rendered quite simple by the use of the synchroscope with its clear indication of vector relations, showing the attendant the proper moment for switch closing.

As in direct current parallel operation, approximately equal terminal voltage must be secured, but now the problem includes the much more critical conditions of approximate speed equality, of same phase rotation, and of sensibly identical vector position, before the paralleling switch can be safely thrown. It is even possible by a device now on the market to have the switches closed automatically when vector relations are correct, relieving the attendant of the strain of his work. This might be likened to the actual dropping of a time ball at high noon automatically, although the preliminary arrangements are manually made in advance. The condition of vector or phase equality must be closely realized, but this can be done after experience even with a relatively large speed difference by causing the switch to close as the indicator passes across the zero mark, just as a bull's-eye can best be secured with the gun sight passing across the target. Also, as in shooting, the time lag of the switch or gun mechanism requires experienced allowance. There is no great difficulty in making a good record under normal operating conditions, but in an emergency when quickness of action is most necessary, undue haste may cause an imperfect switch closing, or possibly as in railway sub-stations an irregular load may make the conditions as indicated by the synchroscope so erratic as to confuse the operator.

A method of self-synchronizing has been devised in which the reactions commonly the result of imperfect switching are so reduced as to permit the switch to be closed at any time regardless of phase relation of the incoming machine. Purposely bad synchronizing produces a mere flicker of the lighting load, and ordinary synchronizing is absolutely devoid of disturbance of any kind. The scheme is merely the temporary insertion between machines (using but one phase in two or three phase machines) of an inductive coil without an iron core. The action of this coil limits greatly the possible current rush on imperfect switch closing without limiting to the same degree the synchronizing power of the machines to pull into step, necessary to complete the process.

It is known that in transformers the initial primary current on switch closing may be abnormal, especially in case of unfavorable

residual magnetism. When two alternators are connected together while differing in phase the magnetism of the two machines cannot be precisely in the relation required for least cross-current, and an abnormal rush of current may result. In case of opposition of phase (180 deg.) the case is equal to a sudden short-circuit resulting in a current rush of perhaps twenty times full-load current, although a gradual but complete short-circuit may not develop more than three times full-load current. This current rush or surge is sufficiently reduced by a rather small coil of wire, whose reactance does not depend upon iron, and which, like resistance, seems instantly ready for duty. A coil costing about one per cent as much as the machine served is often found sufficient for the purpose. The small size of the coil required for self-synchronizing has been a surprise. With such coil it has been found possible to close the switch connecting the bus-bars and a machine to be synchronized before it is even started, when it will easily fall into step upon attaining proper speed. This is not to be recommended, as it will cause an undesirable reaction upon the existing load, unless an unduly large coil be provided.

Experiments have shown that best results are obtained in synchronizing an incoming generator when it is running a trifle "fast," as switching in puts a load upon it, slowing it down. Similarly an incoming converter should be running "slow," as the current flowing into the motor will normally produce motor action tending momentarily to increase speed. Attention to this difference will often prevent an oscillation of machines.

By introducing a large condenser between two machines to be synchronized it has been found possible to hold them at opposition of phase, proving that inductance is necessary in the impedance used for self-synchronizing. Resistance alone is neutral, merely tending to limit the current rush. Too much inductance limits the necessary circulating current too much. The required coil is small, but 50 lbs. of copper in a coil without core serving to permit a 75 kw. 2-phase 60-cycle alternator to be synchronized without reference to phase position.

The use of the self-synchronizing method will not permit alternators improperly driven to operate successfully together. The stringent requirements of the synchronous machines for uniform driving torque has served to greatly improve the regulation of all prime movers, although the problem of engine governing is not yet fully solved. When it is realized that two engines driving alternators in parallel must not vary so much as one mechanical degree in position from uniform rotation, due to cyclic variation, and must change speed simultaneously and equally in case of a change of load, it is seen how difficult the problem is. A certain speed difference is required to operate even an isochronous governor. Too sensitive governing may easily lead to hunting; too sluggish to unequal load division, preventing the use of many units in parallel, or of units differing greatly

in size. A considerable fall of speed from no load to full load in the engines usually increase the ease of operating a generating station, since there is less relative variation among the several engines. Since all engines must run at synchronous speed precisely, they will carry the loads determined by their governors at that speed, and no change of excitation avails to vary the load, as may be done in direct current operation, where a slight speed difference is of no consequence. As may be seen from the chart at a given load capacity the vector position of generator is fixed by its excitation, and any change in excitation will alter its vector position and power factor.

A recent circuit arrangement by which two alternators are connected through the outside connections of a balancing auto-transformer, whose neutral connection goes to line, serves to maintain equal or proportional current outputs from the two machines and permits a considerable excitation difference while maintaining unity power factor, provided the engine powers are arranged to carry the load difference. This method has its special advantage in regulating the outputs of two direct-connected units by means of voltage instead of by currents as heretofore. This permits a considerable load adjustment with equal currents, something hitherto impossible. An interesting feature of the balancing transformer connection for alternators is found in the separation of circulating current from load current, so that any tendency for machines to hunt, even slightly is noticed, and any exchange of current between machines no matter how small may be detected. When the driving power or the voltage is adjusted to give good operating conditions little or no circulating current is found. It is even possible to have an automatic alarm arranged to notify the attendant of any circulating current above a predetermined minimum, the alarm to be entirely independent of amount of load current delivered. Operating is made more certain, the machines will run at unity power factor and armatures and circuits are not encumbered with an unknown wattless current. It becomes safe to operate the plant at higher load factor, and a small unit is protected from overloads due to hunting.

Cyclic variation of speed, especially in gas engines, and variations due to the engine response often falling many electric cycles behind the command of the governor are frequent causes of serious hunting. The recent attempts to improve gas-engine regulation by so radical a step as "bleeding" shows how important the question has become. It would seem that a flexible mechanical or electrical coupling is demanded to make gas engines successful in parallel operation. The steam turbine has such unrivalled advantages in respect to constant speed rotation as to have largely superseded reciprocating engines. The proposed use of asynchronous generators with gas engines will perhaps become the solution of the gas engine problem of regulation.

The use of heavy fly-wheels helps materially in uniformity of rotation, but, in the case of parallel operation, it is a question of the instant dropping of load from a generator which gets so little as

1 deg. in space behind its prescribed position, if it has 30 poles, has not fully as much to do with regulation of speed. If so small a position change removes the load from a generator, the load must be carried by another and the shifting of load due to hunting or to variations of speed not properly termed hunting must overheat the generator rapidly, even when its average load is normal. The slight hunting that will cause at one instant no load, and at the next thrice full load, due not only to carrying its own and its neighbor's load, but also to driving its mate momentarily as a motor, will cause a heat loss somewhat more than twice normal. Moderate hunting will cause surprisingly large momentary loads, and will reduce the apparent rating of the alternator.

All the preceding discussion assumes a pure sine curve of alternating current. The presence of the higher harmonics can add no power for transmission, yet may increase the heat losses in line and in machines. The fact that the triple harmonic is not recorded, even on an oscillograph when connected to the terminals of a three-phase generator, has been the cause of its presence remaining often undiscovered. A vector difference of 30 deg. in the fundamental is 90 deg. in the third harmonic, hence synchronizing at a very moderate phase difference as to the fundamental, may give unexpected prominence to the harmonic. In case of different wave-forms, even having the same equivalent value, dangerous circulating currents may flow. The balancing transformer, previously mentioned, will largely reduce any circulating harmonics.

The sensitiveness of alternators in parallel to slight vector or excitation differences shows that even a seemingly slight unbalanced condition of phases may cause serious overloading of one phase or of the machine. A 5% inequality of voltage as received by a rotary converter might easily cause one phase to produce two-thirds the motor output while the second phase produced but one-third. The synchronous motor, which produces lagging or leading currents at will with a relatively slight change in excitation, might produce a lagging current in one phase, and at the same moment a leading current in another, accentuating a potential difference of an unbalanced line by altering the standard phase angle of current. The action of the induction motor, on the other hand, serves to greatly reduce any unbalanced condition. Synchronous generators and motors require almost ideal conditions for satisfactory operation, and the success of so many transmission lines using rotary converters is proof of the high ability of the engineers installing and operating these plants.

DISCUSSION.

Mr. D. W. Roper, M.W.S.E. Chairman: The subject of alternators in parallel is most interesting and prolific. It seems to be an inexhaustible mine of useful and valuable information. When the stations first began to operate alternators in parallel, the principal thing under discussion was the feasibility or possibility of run-

ning certain types in parallel, and later, as the art progressed, a different line of argument appeared. When direct connected units were built, there was considerable discussion between the engine and dynamo builders: The engine builders thought the dynamos, if properly constructed, ought to hold their machines together with any weight of fly-wheel, and the dynamo builders were very particular about the weight of the fly-wheel. Quite recently, the subject has been interesting locally on account of some of the unexpected occurrences which were noted when attempting to run 4-wire, 3-phase machines in multiple.

DESCRIPTION OF EXPERIMENTS, TO ILLUSTRATE THE PAPER.

The machines used in the experiments were a pair of 125-volt, 3-phase rotaries on the same shaft, located in the Harrison Street station. For the purposes of the experiment one was operated as a D. C. motor driving the other as an 85-volt, single-phase alternator. These machines were originally installed as a pair of engine driven, double current generators, but the engine has been disconnected, and the machines have for sometime been operating as rotaries.

The coil of wire used in the experiment, and which was connected in the armature circuit between the machines and the bus, consisted of 470 lbs. of No. 0 wire, wound on a wooden reel just as it was received from the factory.

A synchronizer, and an ammeter in the armature circuit, were installed in the Society Rooms, and the necessary instrument circuits were extended from the Harrison Street station. The machine was first synchronized in the ordinary way, about 30 degrees out of phase, whereupon the current at the instant of closing the switch was about two-thirds of full load current. The machine was then synchronized a number of times with varying phase difference and with the coil in circuit. When synchronized with a phase difference of 180 degrees, the current did not exceed one-third of full load current.

In the last experiment the switch was closed with a considerable difference in frequency between the machine and the bus and the speed adjusted afterwards.

Mr. Roper: The subject of synchronizing without injury to the machines is one which has occupied the attention of engineers for many years. When the first 1500 k.w. railway rotaries were started in New York City, they were afraid to synchronize those directly with the system in the ordinary manner, for fear they might injure the rotary or disturb the system by setting up surges. They therefore synchronized them for some time by opening the direct current armature circuit and the field circuit at the instant of synchronizing, so that the rotary was connected to the line as an induction machine. That system was modified, somewhat, later by using a separate starting bus supplied by a machine of limited capacity—simply enough to overcome the friction and losses of the rotary. Later on a manufacturing company devised a scheme of starting from the alternating side of the rotaries with a reduced voltage, so that there is no danger at any time of the current exceeding the full load current of the machine.

Another manufacturing company uses an induction motor to bring the rotary up to speed. The system which Prof. Brooks has

shown would possibly not be necessary if synchronizing could always be done under as favorable conditions as it has been done here this evening. In practical conditions the difficulties would be far greater, because there would not be the same uniformity of rotation of either the incoming machine or the bus to which it was to be synchronized.

Mr. Lyman, M.W.S.E.: I have been much interested in Prof. Brooks' paper, and in the clear way he has presented to us the various phases of the subject. Our Chairman, in introducing the speaker, told us that Prof. Brooks would doubtless bring out a great deal more in connection with the subject than had already been considered, and that we should realize after he had finished that there is much yet to be learned. He has shown more than I had thought possible.

When I first began studying the subject I did a good deal of laboratory work with a couple of small alternators, putting resistance and reactance between them to vary this angle, and to get the results so beautifully showing (in Prof. Brooks' charts) the effect of line resistance and line inductance in the synchronizing—and the effect of the difference in impedance in the armature of the alternator or the synchronous motor.

In connection with the use of the coil in synchronizing generators, and possibly, also, in the use of a coil where a synchronous motor is used, the synchronizing power of the two machines is reduced in proportion to the reactance of that coil. Suppose we are driving a synchronous motor, or perhaps a rotary converter: Would not that synchronous motor drop out of speed with an overload much more quickly with this reactance coil in than without it?

Prof. Brooks: Yes, the coil is not left in. It is used like a starting box, and it is possible to cut out the reactance gradually.

Mr. P. Junkersfeld, M.W.S.E.: As I sat here this evening listening to Prof. Brooks' paper and witnessing the demonstration, I was impressed that either the years are passing very rapidly or the art is going on very rapidly, or possibly both. It is perhaps worth mentioning that the particular double current generator used here tonight in Prof. Brooks' demonstrations has been in service only about ten years. At that time the synchronizing of an alternator was somewhat of an event. In fact I believe that was the first double current generator for general lighting and power service which was put into general commercial use. This occurred in 1898. The year before an inverted rotary was put into service—the first 25 cycle installation in Chicago.

Just ten years ago that inverted rotary was synchronized with this machine, which was done by hand and with much hesitancy. At that time very few people cared particularly to take part in synchronizing operations, for if a roof should be torn off they did not wish to be very near. Only a year later the second unit was put in service, and that was the first time the two engine driven units were synchronized and put into use. That was considered important

enough for two experts to come here from Schenectady and spend a week with us. Then in 1900, the first 50 cycle direct coupled alternators in Chicago were synchronized still with some hesitancy. When I contrast those three occurrences with what we have seen this evening, it indicates marked progress.

I recall two or more years ago, when Prof. Brooks pointed out to me what he had been doing in his laboratory—throwing some small alternators into parallel. I confess that I was somewhat skeptical of the outcome, and suggested trying the operation on some larger machines he had next door. He has since done that and more, and I think this is perhaps the first public demonstration on such a large scale. It is an event which is worth remembering, and I have no doubt at all that with small and moderate sized plants particularly the scheme will find quite a little application.

During this interim of ten years devices of one kind or another have been brought out, but most of them have been mechanically operated. Along the lines of automatic synchronizing various devices have been gotten up, but engineers who have been asked the question, "is it worth the money?" have naturally been skeptical, but this device which Prof. Brooks has brought out, which is only a coil of wire, is not open to that objection, and I think the profession is indebted to him for the work he has done along this line during the past two years.

Prof. A. A. Radtke: Several years ago I conceived the idea of putting machines together in this way, but did not know that Prof. Brooks had ever done it. In the laboratory I proceeded to connect up three-phase alternators with some impedance in the circuit, and threw them together in various positions. They came together with more or less activity, depending on the amount of impedance in the circuit. I found that with large impedance in the circuit the machines were slow to respond, while nearer to the condition of throwing them in without any impedance in the circuit they would jump together very quickly. There is liable to be considerable strain on the machines if you throw them in without any impedance.

I am glad to be present this evening and to see Prof. Brooks' modification of the circular diagram. Being familiar with the other versions given in books on the subject of alternating current motors, I think we are indebted to Prof. Brooks for putting this matter in a more simple and direct way, and in a way which is more easily grasped.

Mr. W. L. Abbott, M.W.S.E.: There is one point which I would call attention to:—Prof. Brooks stated that the amount of wire used for this synchronizing demonstration which we have witnessed this evening is between one-half a pound and one pound per kilowatt of capacity of the rotary synchronized. In the next to the last demonstration of synchronizing given, I believe something like 125 pounds of wire was used for 200 kilowatts of capacity. After the switch was closed it took but one or two seconds for the machine to pull in-

to synchronism and I have no doubt the size of the wire in the synchronizing coil could be reduced one-half without any injury resulting to the coil during the operation. We may therefore say that synchronizing can safely be done with as little as ¼ of a pound of wire in the synchronizing coil per kilowatt capacity synchronized. This would be a very small coil hung up on a peg or laid anywhere out of the way.

Mr. E. F. Smith, M.W.S.E.: I have been greatly interested in the paper this evening, but do not know that I can add anything of particular interest in the way of discussion.

It may be of interest to know that the conditions which have required great skill in synchronizing have naturally produced a corps of skilled operators in large systems, and that upwards of 3,000 synchronizing operations are performed per month without any of us knowing it from any bad results being produced; also that we have performed this operation here in Chicago upwards of 100,000 times since we have experienced any damage, and even then the damage was comparatively small, the expense of making the repairs having been only about 0.05 of 1% of the total cost of repairs and reconstruction during the period intervening between troubles resulting from synchronizing, which is quite remarkable.

The generating station at Fisk Street synchronizes about once to each ten times in the sub-stations. I have prepared a few figures, which may be of some interest, although perhaps not largely so, as they are somewhat foreign to the subject. Before enumerating them, however, it might be of some interest to refer to the possible application of Prof. Brooks' scheme of the use of the impedance coil for self synchronizing in connection with starting and putting into service of frequency-changing motor generator sets. That operation as performed in the Commonwealth Edison system, where we convert from 25 to 50 cycles, is quite an important one, as the motors, having five pair of poles, present five different conditions under which it is proper to connect them when synchronizing with the 25 cycle system, although one only is correct for paralleling the 60 cycle generators and that involves starting the motor on the A.C. side, observing the displacement between the generators, disconnecting motor and sliding round until the generators are in step, then closing them together. It might be possible, with the application of the impedance coils of Prof. Brooks' scheme, to so design them in regard to their relative strength, that with one connected in each end of such a unit—in the 25 cycle end as well as the 60 cycle—the mere closing of those two circuits would automatically bring the machines into correct phase relationship on both sides; this would save time and be a desirable condition if practicable.

The impedance coil may be applied to rotary converters in synchronizing before cutting them in, although the presence of such an impedance between the A.C. terminals of the transformer connected with the rotary and the bus involves, when connecting the rotary

with the transmission system, with a phase displacement existing between the two, a lagging current through the armature of the converter, which will cause it to speed and may create a very undesirable condition. In order to avoid such speeding Prof. Brooks has applied an additional impedance coil to the D.C. side of the converter, the value of the impedance being such, relatively, to that of the coil on the A.C. side, that the tendency to speed would be counteracted.

Recently when I was visiting the University of Illinois, Prof. Brooks was kind enough to demonstrate the operation of synchronizing a small rotary converter, both with the impedance on the D.C. side and without it. The operation of synchronizing without the impedance in D.C. side resulted in excessive speed, but the operation was very successfully performed with the impedance on both sides.

As to whether there would be required a separate impedance coil for use in D.C. side with each particular converter, is, I think, somewhat of a question and might have some bearing on the applicability to rotary converters. It is a very valuable method, and one capable of wide application but more particularly applicable to generators.

The proportional amount of time consumed in the operation of synchronizing purely and simply, as compared with the total time required in starting rotary converter outfits, may be of some interest. The entire time required for performing operation of synchronizing alone—I mean the time required under the most favorable circumstances for that particular operation alone, separate from everything else—ranges from five to fourteen seconds, with the different sizes of converters ranging from 500 k.w. to 2,000 k.w., and correspondingly ranges from eight to fifteen per cent. of the total time required to perform all of the starting operations of the converters.

In regard to the method of starting the converters, practically all the starting of converters in the Commonwealth-Edison system is done by the D.C. method, and but comparatively few of the converters in that system are equipped with switches which may be used in connection with the half taps on the transformers, for starting the converters from the A.C. side by impressing upon them one-half the full A.C. voltage. Under the latter conditions converters can be started, in general, quicker than by the D.C. method.

I will state, briefly, a few figures in connection with A.C. starting. They may look like discrepancies, but it will be observed that the stored energy at synchronous speed is somewhat different for the different machines, and the time required for acceleration is correspondingly different. The maximum k.w. and amperes drawn from the generators during the starting of the converters from the A.C. side is

300 k.w. for 250 k.w. converter; 20 amperes;
290 k.w. for 500 k. w. converter; 30 amperes;
475 k.w. for 1000 k.w. converter; 54 amperes.

A large amount of energy is consumed in overcoming the inertia of the armature. The *average* k.w. during the entire period is with

250 k.w. converter, 101;
500 k.w. converter, 200;
1000 k.w. converter, 233.

giving percentages of rating ranging from 36 per cent. for the 250 k. w. converter down to 21 per cent. for the 1000 k. w. converter.

The periods of acceleration were as follows:

8½ seconds for 250 k.w. converter;
9 seconds for 500 k.w. converter;
19.3 seconds for 1000 k.w. converter.

It will thus be seen that these machines speed up very rapidly. The stored energy in k.w. minutes in the revolving mass at synchronous speed, which amounts to the same as the energy required to accelerate to synchronous speed is:

14.3 for 250 k.w. unit;
30 for 500 k.w. unit;
75.1 for 1000 k.w. unit.

The time required for completing all starting operations from the A.C. side, ranges from

38 seconds to 1 min. 6 sec. for the small machine—250 k.w. unit;
53 seconds to 1 min. 8 sec. for the 500 k.w. unit.
1 min. 3 sec. to 1 min. 53 sec. for the 1000 k.w. unit

The large difference in time resulted from the methods used for correcting polarity. The method was that of reversing the field current by the reversible field break-up switch, the shortest time being that in which the polarity was corrected by exciting the field from the D.C. bus.

Mr. Geo. H. Lukes, M.W.S.E.: I am sure that every man that has anything to do with the operation of alternating current power plants will be greatly interested in this scheme. It certainly has very attractive possibilities. It is cheap for one thing, and we do not need to add to our intended investment a very large amount to "try it out."

I think there is only one point on which Prof. Brooks deserves censure and that is that he did not bring out the scheme a number of years ago. His efforts to snap the rubber bands on the bicycle wheels reminded me very much of the daily performance at a little station that we operated, where sometimes the chief engineer was trying to parallel machines, the load going up every second. I think Prof. Brooks sort of deprecates the scheme and tries to make us believe that it would be applicable to special conditions, but those special conditions under which it would be a very nice thing are the ones that get us into trouble with our customers. I have an idea that, as the operating force becomes more thoroughly organized and as the equipment of a plant or system is modernized and everything

is running smoothly, a shut-down, when it does occur, is likely to be more disastrous, and the recovery is likely to be slower than in old plants where such things were of daily occurrence. I know that with the Commonwealth-Edison Co., the operation became so perfect that every once in a while they would have a "mock" breakdown, just to keep the employees in training. I believe Mr. Smith organized something similar to a fire drill: he would put part of the system out of use and start it up again so the employees would know how to start up when there was a shut-down.

The point I am trying to make is that such a device as Prof. Brooks proposes might be of tremendous importance, even in a well organized company with modern equipment.

Mr. Phenicie: I have been much interested in Prof. Brooks' talk. In operating our moderate sized plant we have more trouble in staying in synchronism than we do in getting in, in the first place. That is, we will have quick variations of load which will throw us out of synchronism after we have been operating for some time. It occurred to me that this reactive coil would be very valuable to put in between the stations and leave it there permanently, if properly designed.

Prof. Brooks: If the coil was left in permanently, it would tend, to a certain extent, to hinder the flow of synchronizing current and assist in pulling out of step.

NEW QUARTERS FOR THE WESTERN SOCIETY OF ENGINEERS

Chicago, June, 1908

The Board of Direction of the Western Society of Engineers, desires to inform the membership and friends of the Society what is being done in the way of improved accommodations.

The accompanying engraving shows the proposed changes on the 17th floor of the Monadnock Block, which additional space has been secured for the use of the Society.

The space heretofore occupied, was a suite of offices, on the east side of the building, and known as Nos. 1734-41 inclusive. Under the new arrangements the rooms 1736-41 inclusive have been vacated and the new space includes all of the 17th floor north of the elevators, to the fire wall at the mid-length of the building. This includes the corridor, and the rooms on each side thereof, known as No. 1760-64 and 1731-35, inclusive. As shown on the plan, this gives a floor space of 62 ft. by 61.5 ft., an increase of more than 80% over the old quarters.

A wide double glass door will close the end of the corridor next the elevators and the present corridor walls will be taken out and rearranged as shown in the plan.

In the central portion of the new space will be the meeting room, 36 ft. by 44 ft., with a high ceiling and seats for 162—an increase of 60% over the old quarters. It is expected that the ventilation of this new meeting room will be much better than heretofore. The reading room will remain and be virtually as heretofore, and with the Secretary's office on the opposite side of the building, with an entrance vestibule between. Adjacent to these will be the Library, on the east side, and a committee room and store-room for periodicals on the west side of the building. This arrangement, it is believed, will give increased space for the needs and convenience of the Library, which is steadily growing and is used more and more by the membership and the public.

The membership now numbers 1000, of which about 60% are "Resident," living within 50 miles of the Society's rooms. The rest of the membership are scattered over the United States and dependencies and are also to be found in Mexico, Cuba, South America, etc.

The meetings of the Society are generally held twice, and sometimes three times, a month, except in July and August, and aggregate about thirty meetings a year. At these meetings subjects of engineering or technical interest are presented, by means of papers and addresses, and are open for general discussion afterwards. These papers and discussions are subsequently published, with suitable illustrations if desirable, in the JOURNAL of the Society, which is distributed to the membership. The JOURNAL can also be had from the

Secretary, by purchase or a subscription of $3.00 a year. The JOURNAL is issued six times a year, under the dates of February, April, June, August, October and December. These six numbers of one year constitute a volume; a copious index for the year is printed with the December number.

The publication of the JOURNAL of the Society began in 1896, and the issues for the current year, 1908, constitute the 13th volume. The Society was organized in 1869, nearly 40 years ago, as the "Civil Engineers' Club of the Northwest," but was incorporated under the laws of the State of Illinois in 1880 as the Western Society of Engineers. The Society has always maintained something of a Library, but this was not extensive nor of great value until after 1896, when the publication of the JOURNAL was begun. By its aid, the Society was placed in closer touch with other Engineering, Scientific and Technical Societies, the publications of which, as also a considerable list of technical and engineering papers come to the library of the Society, in exchange for the JOURNAL. There are about 200 such publications that are received on this basis and these constitute a valuable and interesting part of the Library.

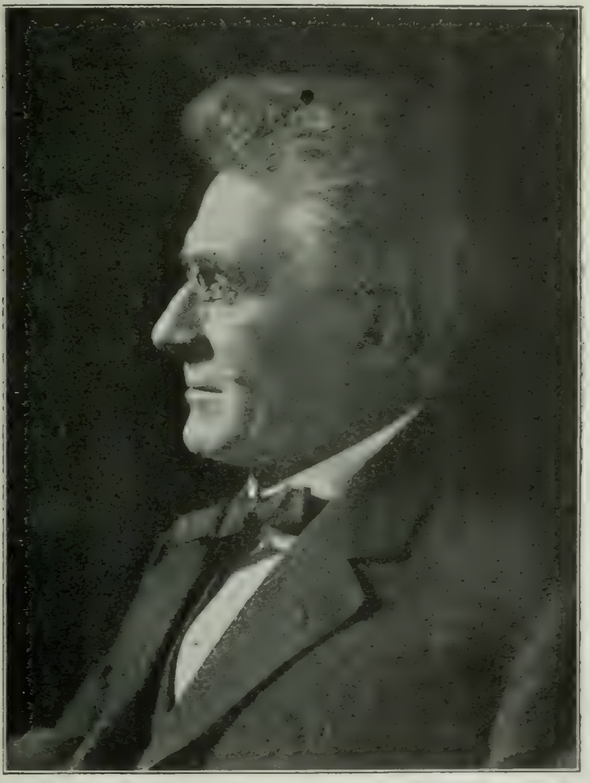
Many books come to the Society, from publishers, in consideration of a reading notice or review of the book being published in the JOURNAL. Other books are bought from time to time by the management of the Society, as it may seem expedient, and the Library now contains nearly 7,000 volumes of Engineering, Scientific or Technical interest. The central location of the rooms and library of the Society, in the Monadnock Block, makes them very accessible and the Library is constantly patronized by the members of the Society and others. It is hoped and expected that with the new quarters of the Society, the Library will be still more available and valuable for consultation.

IN MEMORIAM.

Professor Storm Bull, M.E.

November 17, 1907.

Storm Bull was born at Bergen, Norway, October 20th, 1856. His early education was obtained at his home in Norway, but for his professional work he went to Switzerland where he attended the famous engineering school at Zurich, at that time the most cosmopolitan technical school in the world. He chose the course in mechani-



cal engineering, from which he graduated with the degree of M.E. in 1877. The cosmopolitan character of the institution was of great advantage to him as he was compelled to listen to lectures in at least two different languages (French and German), both foreign to him. In this way Professor Bull laid the foundation for an exceptional proficiency in the use of modern languages, both in speaking and writing.

After graduation he spent two years in engineering practice, mostly in European shops. He came to this country in 1879 and chose Madison, Wisconsin, as his residence, being led to this choice by reason of the fact that Ole Bull, the great violinist and an uncle of Professor Bull, resided there at that time.

Shortly after his arrival he was appointed instructor in the engineering department of the University of Wisconsin, in which position his work varied from time to time as the contingencies of the program might require. He was appointed professor of mechanical engineering in 1886; and, in 1891, by reason of increasing specialization of work, he was made professor of steam engineering. This chair he held up to the time of his death.

Professor's Bull technical training was of the highest order, and his working knowledge of mathematics and the higher methods of analysis was equalled by very few men in American engineering schools. In the development of the modern high-duty engine, and of the steam turbine, Professor Bull was quite at home, and his critical reviews for the Engineering News, of technical work in this field, have attracted much attention.

While first of all a teacher and scholar, Professor Bull was active in professional practice, particularly during recent years. His services were frequently required by his home state in the design of power plants for various state institutions, and at the time of his last sickness he was engaged in the preparation of plans for a large power plant for the new Wisconsin State Capitol building. He was an honored member of many scientific and technical societies, and was particularly active in the Society for the Promotion of Engineering Education, the Western Society of Engineers, and the American Society for the Advancement of Science.

To those acquainted with Professor Bull nothing need be said regarding him as a gentleman and a man of the highest honor. His devotion to duty was a strong element in his character, and to him this demanded his services, not only in his profession as a teacher and engineer, but in all of his relations to society. It was this that led him to give his time for several years as a member of the common council and as mayor of the city of Madison. He was also for many years an active member of the finance committee of the Unitarian church, to which he belonged. He had just reached the prime of life and was most enthusiastic regarding future plans in his professional work.

In the spring of 1907 Professor Bull was attacked by cancer and, while an operation appeared for a time to relieve him, the trouble returned and, after many months of suffering, he passed away on November 17th, 1907. He leaves a wife and son, a recent graduate of the University of Wisconsin. (Signed)

F. E. Turneaure,
L. P. Breckenridge,
Andrews Allen,
Committee.

James Dun.

February 23rd, 1908.

James Dun was born in Chillicothe, Ohio, September 8th, 1844, his parents being James and Susan Virginia Walke Dun. His father's ancestors were Scotch and his mother's English. He was educated in the public schools of Ohio, and in Miami University. In 1866 he began his railroad experience as a chairman with an engineering party

on the Indianapolis & Cincinnati Railway, a line which is now a portion of the Cleveland, Cincinnati, Chicago & St. Louis Railway. The following year he entered the service of the Atlantic & Pacific Railway and served with that company as an Assistant Engineer until 1871, the Atlantic & Pacific at that time being the name of the road which afterwards became the St. Louis & San Francisco Railway. The original purpose of the incorporators of this company was the construction of a line to the Pacific Coast, and Mr. Dun was engaged thus early in investigations and surveys in connection with a trans-continental line. In 1871 Mr. Dun went to the Missouri Pacific Railway as an Assistant Engineer and stayed with

that company until 1874 when he was engaged as Engineer for the Union Depot Company at St. Louis, Mo. In 1877 he became connected with the St. Louis & San Francisco Railway, which had meanwhile succeeded the Atlantic & Pacific Railway, as Superintendent of Bridges and Buildings, and the following year he was made Chief Engineer of that road. Twelve years thereafter the Frisco, by which name the St. Louis & San Francisco Railway was known, became part of the Atchison, Topeka & Santa Fe Railroad, and Mr. Dun was made Chief Engineer of the latter in August, 1890, his headquarters being established at Topeka. He remained with this company up to the time of his death, having been made Chief Engineer of the entire Santa Fe System, with headquarters in Chicago in 1900, and serving in this capacity until 1906 when he became its Consulting Engineer.

When Mr. Dun was born there were practically no railroads west of the Great Lakes and at the end of his life seven trans-continental roads reached to the Pacific with many extending from the northern boundary of the United States to the Gulf, and the entire country had been thoroughly opened up and developed by this powerful agent and forerunner of civilization. Mr. Dun, born as he was, in the great Mississippi Valley and passing his entire life in that region contemporaneously with this remarkable development of railroads therein has left a distinct imprint, not only on the work as a whole, but on the characters of the men who served under and with him. His life, therefore, may be counted as woven into and a part of this great network of transportation lines that have been created in the western half of this great country. Mr. Dun kept pace, not only with the growth in mileage of the railroads of the west, but with the developments in quality and character of the transportation facilities demanded and afforded by the more recent years. As an example of the later and better type of construction may be cited the two hundred and fifty miles comprising the Eastern Railway of New Mexico, a part of the Santa Fe System, built entirely under Mr. Dun's supervision during the latter years of his service as Chief Engineer, a road built over an elevation over six thousand feet high with limiting grades of only six-tenths of one per cent and with workmanship of a character that will always stand as a monument to Mr. Dun's ability in this direction.

In the course of his long connection with the various western roads many interesting engineering problems were presented to him and successfully solved. While he was Chief Engineer of the Santa Fe System the work of rehabilitation was carried out by which practically every bridge on its main line was strengthened or renewed in order to modernize the road and enable it to carry the heavy power which economical conditions have forced the railroads to adopt in recent years. This was no light task on a road which had recently been through financial difficulties and which extended over such an enormous territory. Following close on the successful carrying out of this work came the track elevation work in Chicago and the

many problems and difficulties attached thereto, all of which bear the imprint of Mr. Dun's abilities, and the successful carrying out of which in many cases was due entirely to his plans.

One of the most important works of Mr. Dun's life was the tabulating of drainage areas in the territory covered by the lines in which his experience has been gained. By means of the tables prepared under his direction a systematic design of openings for waterways has been rendered possible and Mr. Dun was one of the pioneers in this method of determining the size of structures necessary.

In 1885 Mr. Dun married Mrs. Belle R. Otterson, and their daughter, Mary E. Dun, survives both parents.

Mr. Dun's second wife, Mrs. Lucy J. Rucker, to whom he was married in 1899, survives him.

The subect of this memoir was an example of rugged, straightforward manhood, combined with simplicity of character. A love of justice and fair dealing actuated his course through life.

One of the subscribers to this memoir of our late comrade, had to negotiate with him a settlement affecting his railway system on the one hand, and the Sanitary District of Chicago on the other. This negotiation was somewhat intricate and very protracted, and through it the two men came to know each other intimately. To the one who lives to write of his friend it demonstrated his patient industry in thorough investigation of every detail of the questions involved, but more than all it demonstrated his absolute fairness; he sought justice, not advantage. Often since then the conviction born of that negotiation has found utterance like this "If I had a matter to be arbitrated I would be willing to have Jim Dun the sole arbitrator, and would know that his decision would be just."

Mr. Dun was a member of the American Society of Civil Engineers, of the Engineers Club of St. Louis, and of the Western Society of Engineers, having been elected a member of the latter on March 17th, 1896.

(Signed

ONWARD BATES,
ISHMAN RANDOLPH,
W. B. STORY, JR.
Committee.

PROCEEDINGS OF THE SOCIETY.

MINUTES OF THE MEETINGS

Regular Meeting, May 6th, 1908.

A regular meeting of the Society (No. 633) was held Wednesday evening, May 6th, 1908. The meeting was called to order about 8:25 p. m., with President Loweth in the Chair and about 70 members and guests present.

The minutes of the meetings of the Society held April 1st and 15th, were read and approved.

The Secretary reported from the Board of Direction the election into membership of the following:

	Grade.
A. C. Greaves, Sturgeon Bay, Wis	Active
Henry H. Decker, Winona, Minn	Active
Charles W. Naylor, Chicago	Active

Also that the following had applied for membership:

Fred K. Boomhower, Chicago.
Henry F. Gaston, Chicago.
Lewis M. Martin, Watertown, Wis. (Transfer).
F. E. Hermanns, Tientsin, China. (Transfer).
J. W. Phillips, Lewiston, Cal.
Rudolph S. Blome, Chicago.

The Secretary announced a change in the program of meetings; namely, that at the next meeting of the Society, to be held about May 20th, Dr. P. H. Dudley, of the New York Central Railroad Co., would address the Society on "Steel Rails for present service; their manufacture and failure."

Mr. W. L. Abbott presented a resolution as follows:

"Whereas, The members of the Western Society of Engineers realize the great injury done the natural resources of the country by the wasteful methods often employed in their development, and

Whereas, The President of the United States is calling the attention of the country to the fact that such unnecessary waste should, in the interest of present and future generations, be stopped, and to this end has called a conference of Governors of Sates, Members of Congress, representatives of engineering societies, and others, to consider what steps should be taken for the better conservation of our natural resources, be it

Resolved, That the Western Society of Engineers does heartily approve of the purpose of this conference, and trusts that its deliberations will suggest ways to secure the development of our natural resources without the great waste which has been incident to their exploitation.

Resolved, That copies of these resolutions be sent to the President of the United States, to the Senators and Representatives in Congress from the State of Illinois, to the Governor of this State and his special advisers."

This was duly seconded and acrried.

Mr R. H. Kuss, on behalf of Mr. John W. Alvord (who could not be present) presented the following resolution:

"Whereas, The growing importance of the streams of the United States in relation to navigation, irrigation, water supply and water power, renders it of the highest importance that all of their physical characteristics be ascertained and recorded in a uniform manner by a central authority, such as the Geological Survey of the United States Government, and,

Whereas, The work of this bureau has been curtailed by insufficient appropriations, to the great detriment of the public interests, under the mistaken notion that it served private interests merely, and,

WHEREAS, The proper study of the disastrous results of deforestation, and the value of careful regulation as affecting the values of our rivers for navigation, irrigation, water supply and water power can only be undertaken intelligently by the aid of carefully collected data of stream flow; and, further, that the engineering, financial and economic measures which must be undertaken to derive the full value of our streams can only be properly based upon exact knowledge of such run-off data properly secured, and,

WHEREAS, A bill known as House Bill No. 6122, was introduced Dec. 9th, 1907, to provide for this important work, and is now before Congress. Therefore, be it

Resolved, That the Western Society of Engineers believes that this is a Federal undertaking of the highest importance, which cannot be properly left to other authority. That much valuable information has already been collected by the Government, and recorded by it in its Water Supply and Irrigation Papers, which would have been lost to general use if left to State or private development, and that the cessation in the collection of this important data is a grave mistake, which should be not only rectified at the earliest possible moment, but the work further enlarged and extended, and, be it further

Resolved, That the Society earnestly recommends to Congress the adoption of House Bill 6122, or suitable legislation of a similar character, and that copies of this resolution be forwarded to Members of the Rivers and Harbors Committee, by the Secretary of this Society, and that the individual members of this Society urge upon their respective Congressmen the propriety of the passage of this or similar legislation."

This was duly seconded and carried.

Prof. J. C. Thorpe, M.W.S.E., of the University of Illinois, was then introduced, who presented his paper on "Steam Turbine Development." As the paper had been printed and sent out in advance of the meeting it was not read in full, but the author gave the substance of it in a talk, illustrated with numerous lantern slides. Discussion followed from Messrs. W. L. Abbott, A. W. Moseley, C. G. Y. King, Wm. B. Jackson, E. F. Smith, P. Junkersfeld, A. Bement, President Loweth and the author.

The meeting adjourned at 10:30 p. m.

EXTRA MEETING, May 18th, 1908.

An extra meeting of the Society (No. 635) was held Monday evening, May 18th, 1908. The meeting was called to order about 8:10 p. m. with Past-President Finley in the Chair, and about 75 members and guests present. There being no business to bring before the Society, the Chairman at once introduced Dr. P. H. Dudley of the New York Central R. R. Co., who read his paper on "Steel Rails for present service; their manufacture and their failures." After the reading of the paper a considerable number of lantern slides were shown, illustrative of the subject, which were explained and commented upon by Dr. Dudley as they were shown.

Remarks followed from Messrs. R. W. Hunt, W. H. Finley, J. R. Budd and the author.

The meeting adjourned about 10 p. m.

REGULAR MEETING, June 3rd, 1908.

A regular meeting (No. 636) was held Wednesday evening, June 3rd, 1908. The meeting was called to order about 8:20 p. m. with President Loweth in the Chair and about 45 members and guests present.

The minutes of the meetings of May 6th and 18th were read and approved. The Secretary reported from the Board of Direction, the election into membership of the following:

	Grade.
Walter T. Ray, Pine Beach, Va., transferred from Junior to..........	Active
John H. McElroy, Chicago....................................	Active
William J. Crumpton, Chicago....................................	Active
Fred K. Boomhower, Chicago....................................	Active
Frank E. Hermanns, Tientsin, China, transferred from Junior to......	Active

Also that the following had applied for membership:

Lloyd E. Ross, Chicago.

Joseph C. Worrell, Janesville, Wis.

Mr. Layfield offered a resolution, which was duly carried, that the meetings of the Society be discontinued during July and August, on account of the generally warm weather, and owing to the expected changes in the rooms of the Society there would be no meeting room those months.

President Loweth offered some remarks as to the action of the Board of Direction, in leasing increased space in the Monadnock Block for the use of the Society, stating that plans had been prepared for the arrangement of rooms in this increased space; that this increase of space is about 80% over what the Society has had for many years; that the meeting room would have a capacity of about 60% more seats than the old meeting room; that the Library would have a considerable increase of capacity for books, etc., and that it was hoped and expected that the changes would all be made before the first regular fall meeting to be held September 2nd, on which occasion it was expected to have an address from Mr. H. von Schon of Detroit, on study of a hydro-electric plant.

The Secretary distributed some slips, with an engraving showing the plan of the new quarters.

There being no further business the President introduecd Mr. E. M. Griffith, State Forester of Wisocnsin, who addressed the meeting on "The Conservation of the Forests and Water Powers of Wisconsin." This was illustrated by many lantern slide views.

Discussion followed from Messrs. E. N. Layfield, W. L. Abbott, Wm. B. Jackson, President Loweth, and Mr. Griffith.

The meeting adjourned about 10:10 p. m.

J. H. Warder, *Secretary.*

ELECTRICAL SECTION.

Minutes of Meeting of May 8th, 1908.

A regular meeting, No. 33, of the Electrical Setcion (being No. 634 of the Society) was held Friday evening, May 8th, 1908.

The meeting was called to order by Mr. D. W. Roper, Chairman, at 8:30 p. m. The minutes of the meeting of April 10th were read and approved.

There being no further business before the Setcion, the Chairman introduced Mr. F. R. Babcock, who addressed the meeting on "The Electrical Equipment of Steam and Gasoline Automobiles." Some interesting apparatus was exhibited in illustration of the paper.

A conversational discussion followed from Messrs. Ernest Lunn, E. F. Smith, G. H. Bentley, Edwin Smythe, C. K. Baldwin, the Chairman (Mr. Roper), and Mr. Babcock, the author of the paper.

The meeting adjourned at 9:45 p. m.

J. H. Warder, *Secretary.*

EARTHWORK COMPUTATION—METHODES. By C. W. Crockett, Professor of Mathematics and Astronomy, Rensselaer Polytechnic Institute. 1st edition; pp. 114; 97 figures. Cloth. $1.50 net. New York, John Wiley & Sons. 1908

To the engineer accustomed to using without question the method of average end areas in computing earthwork quantities, an examination of this book is somewhat startling. The prismoidal formula, because of the tedious calculations involved in its application, is not generally used unless, for special reasons, great accuracy is desired. At the same time it is recognized as the only theoretically correct method of making such computations. It is therefore a distinct advance in practice when a simple method for applying this formula is proposed, bringing it within the range of practical computation for ordinary purposes.

The development of the special method for using the prismoidal formula appears to be the most important part of the book. But there are also chapters on the average end area method with an outline of corrections to be applied to a volume computed by this method in order to secure the same accuracy as with the prismoidal formula. Other chapters deal with correction for curvature in railroad work, and with an explanation of the construction and use of the Crockett Volume Slide Rule.

It may be well to note that perhaps the greatest objection to the prismoidal formula is in the labor involved in obtaining the area of the mid-section. The methods proposed by the author eliminate this labor to a great extent. The formulas as printed look complicated, but are apparently simple in application. On the other hand, and this is the only criticism to be offered, this method is special to a great degree and could not be picked up and used readily after a long period of disuse.

The book is well printed and the figures are clear and illustrate well the points involved. J. E. M.

THE BLAST FURNACE AND THE MANUFACTURE OF PIG IRON: By Robert Forsythe. New York. 1908. David Williams Co. 9¼ by 6¼ ins. Cloth bound. 368 pp. including index. Over 50 illustrations and many tables. Price $3.00.

"An Elementary Treatise for the use of the Metallurgical Student and the Furnaceman" is the subtitle for the book, which on examination seems to be a very modest statement of the case. The first 20 pages is Introductory matter relating to the classification, constitution, and physical properties of cast iron.

This is followed by Chap. I on "Materials of Manufacture" as ores (and the preparation of the same), fuel and fluxes. Description of plant is detailed in Chap. II as the furnace, stoves, cast house, boiler plant and blowing engines. Chap. III describes the operation of the furnace as "Blowing In" and handling products, while Chap. IV gives the "Burdening of the Furnace," and concerns the slag, control of hearth temperature, and the theoretical and empirical phase of the burdening. The action within the furnace is considered in Chap. V, as the descending current of solids and ascending current of gases, with the interactions of these currents; chemical reactions; heat development in the furnace, and heat requirements, etc. A very serious matter to the Furnacemaster—"Furnace Irregularities"—is the subject of Chap. VI, while hints on design and equipment are treated of in Chap. VII.

Following these comes the "Supplement," pertaining to cast iron in its varieties and uses, and Appendix I, relating to "Some Principles of Chemistry and Physics," is a valuable and suitable chapter for the conclusion of the book. The work is an admirable one and contains much information that has only recently been available except by prolonged search through the technical press and the publications of the mining and metallurgical societies. Of

course there are some few eminent men among the managers of blast furnaces, who after years of practical operation of their properties know what is contained in this book, but there is much here that will be found instructive to students and to the younger men engaged in and about the blast furnace. An admirable feature in this publication is marginal references as to the source or authority for statements in the text, as the "Iron Age," "Trans. American Institute of Mining Engineers," "Iron Trade Review," Iron and Steel Institute," "American Society of Testing Materials," "Engineering News," "Engineering and Mining Journal," etc. As blast furnace operations are essentially chemical, the chemistry of the operation is well set forth with the neecssary calculations for a complete understanding of the "reason why" of the processes followed, especially when changing the raw material.

Stationary Steam Engines, by William H. Fowler, Wh. Sc., M. Inst. C. E., M. Inst. Mech. E., M. Iron & Steel Inst., &c. Scientific Pub. Co., Manchester, England, Cloth 7¾ x 10, pp. 295, 12s, 6d.

The author's stated purpose in compiling this book "is in the main a reproduction with emendation of articles which have appeared at various times in the columns of the Mechanical Engineer, and which at the suggestion of a number of readers have been revised and collected for greater convenience of reference."

A brief introduction relates the history of the development of the steam engine, and points out the fact that the inventions of James Watt embodied practically all of the main principles common to modern engines, and that the improvements during the last century have been in the nature of mechanical refinements and the carrying out of the fundamental principles to a higher degree.

The book is well printed in large type and contains over 300 illustrations, showing carefully selected examples of current practice, with working drawings of various designs, and a considerable number of curves and diagrams. All questions are treated from a strictly practical view point in a clear and concise manner, and are illustrated with typical examples free from complicated mathematical expressions or difficult technicalities.

The different types of engines and the general principles of their design with regard to maintenance and operating efficiency are reviewed in connection with sufficient theory to interestingly disclose the underlying principles. Typical indicator diagrams and expansion curves are shown together with tables giving mean effective pressures under various conditions, and also tables giving the number of expansions for various cutoffs, all in a form easily understood.

Characteristic curves disclosing the water consumption under various conditions of load, super-heat, etc., are shown for different types of engines. The various factors governing the steam consumption are discussed and records of various engine tests are printed.

The practical considerations entering into the design of the various parts of an engine are thoroughly considered and illustrated by numerous working drawings. The author not only states the characteristics of good design, but also points out various features to be avoided.

A large number of drawings and photographs illustrate types of both slow speed and high speed engines. The examples are drawn largely from types manufactured in England and on the continent, but include several typical American designs.

Considerable attention is given to discussion of different styles of valve and valve gears with numerous well selected illustrations.

The characteristic features of slow and high speed engines are presented and conclusions drawn, showing the relative advantages of each type, and their spheres of usefulness. The advantages of governing either by throttling or cutoff are plainly set forth with a view to showing the relative advantages and adaptability of the two methods.

Illustrations of the various types of governors are shown and their operation explained.

The construction and design of fly wheels are taken up and illustrated by means of an extended example showing the practical design of a fly wheel to meet an assumed condition.

A chapter is devoted to lubricating arrangements, and the ordinary gravity system, the splash system and the force system are quite fully taken up, together with drawings showing the different methods of applying each system, though no consideration is given to any central distributing system. The importance of good lubrication is well set forth.

The jet and surface condenser systems are discussed in some detail, and illustrated by several drawings.

The author's general plan is to illustrate and describe typical examples of steam engines, point out their chief characteristics, and discuss in general the special adaptability of the various kinds and types.

This work will prove interesting reading to anyone desirious of obtaining a more or less elementary knowledge of steam engines and condensers.

W. J. C.

Railway Shop up to Date. A reference book of American Railway Shop Practice, by the Editorial Staff of the Railway Master Mechanic. Crandall Publishing Co., Chicago, 1907. 9 by 12 in.; cloth bound; 243 pp. including index; 107 full page line engravings and 12 full page half-tone illustrations.

The railway official, or designer, having under consideration plans for remodeling an existing shop plant, or the building and equipping of a new shop, seldom undertakes the work without first making a study of successful shops already in operation to find what is best in design, construction and equipment. A large amount of matter descriptive of many of the more modern shops has appeared in the technical press in late years, but to the one seeking information it would prove an almost endless task to sift it all and find the particular data which would be of use. The Editorial Staff of the "Railway Master Mechanic," under the direction of Mr. Maham H. Haig, Managing Editor, has undertaken this task with admirable success and through the co-operation of the railway officials of this country, is able to present a work which is a compilation of what is found to exist as the best in railroad shop practice, design and equipment, without attempting to theorize on ideal conditions. The Editor divides the work of 240 pages into eleven chapters, though through an error in the numbering omits Chapter VII.

Chapter I is introductory and Chapter II deals with the Layout. It is not attempted to lay down any fixed or established rule for the grouping of the buildings as it is conceded that every shop arrangement must be influenced by size, shape and topography of the available land or, in the case of remodeling the old shops, the use of the present layout and the conditions of the plant must be considered. Particular attention is paid to the transfer table and the grouping of the buildings for service with this equipment. The variety of opinion which exists as to the best use of the transfer table is well shown by the plans of several of the more modern layouts which are given at the end of the chapter.

Chapter III takes up the Locomotive shop. Careful consideration is given to the design of the buildings with reference to the class of work to be handled and examples are given of shops for general and heavy repairs as well as those for the building of complete locomotives. Lists of tools in use in several representative shops and cross sections, elevations and plans of a number of buildings selected as distinctive types of modern shop design are included.

Chapter IV deals with the Blacksmith Shop and discusses very thoroughly the location, size and equipment of the building. The chapter concludes with a list of tools in use in a few shops and sections and plans of representative buildings.

Chapters V and VI take up the Freight Car and Passenger Coach and Paint Shops. The proper lighting and heating of the paint shop is empha-

sized and numerous elevations, sections and plans showing details of construction of buildings with particular reference to these features are shown.

The Planing Mill is considered in Chapter VIII and very complete lists of the woodworking machinery in use in a number of the more modern shops, together with plans showing the arrangement of the equipment, are included.

Chapter IX is devoted to the Foundry. Until very recent years a foundry was not considered a necessary part of a railway shop plant, but since 1902 a number of the larger shops built have included this equipment and nearly all of the shops now under construction, or contemplated, have made provision for a foundry. Plans and sections of a number of typical buildings are shown.

Chapter X deals with the Power Plant. Until about fifteen years ago the general practice was to locate the power plants as an annex to the principal shop buildings in such a manner that the engines could drive long line shafts. The introduction of electrical equipment has completely changed these conditions and the modern power plant now consists of a single building in which is generated electrical power for the entire shop plant. The various systems of fuel and ash handling in use in a number of the newer plants are also considered. The chapter is followed by a number of pages of cross sections, elevations and plans of many of the newer plants as well as several diagrams showing the arrangement for distribution of electrical energy.

Chapter XI considers the Storehouse. Modern practice has been to establish a general base of supplies for an entire system at the main shop plant. This requires a careful loaction of the storehouse and yards so that rapid distribution of material can be made, either to the shop buildings or for shipment to sub-stores. A number of plans and elevations of some of the newer buildings and numerous photographs of interior arrangements, equiped for the handling of material and the disposition of material in storage yards are included at the close of the chapter.

Chapter XII is devoted to the Roundhouse, with its necessary adjuncts, the water and coaling station. The editor recognizes the difference of opinion which exists among officers and designers as to the most efficient type of roundhouse, as well as to the arrangement of the terminal yards, and he does not attempt to point out the particular advantage of any type of building or of any yard arrangement, over another, but at the end of the chapter he presents a number of plans of buildings and yard layouts which are considered as representative of modern practice. The drop pit, cinder pit and washing out systems in use by the different roads are discussed and shown in detail by drawings and a number of sections and elevations of a few of the many coaling devices are given.

The work also includes a very complete list of "References to Articles Descriptive of Railway Shops" arranged alphabetically according to the railroad systems, from the years 1899 to the present and a list of "References to General Articles ConcerningRailway Shops" which have appeared in the technical press and in the proceedings of the engineering societies during the past six years.

W. A. H.

VEST-POCKET HANDBOOK OF MATHEMATICS FOR ENGINEERS; by L. A. Waterbury, C. E., University of Arizona. John Wiley & Sons, New York; 1908. Leather bound. Price $1.00.

This is a handy little book for the pocket; size 2¾ by 5½ ins., and of about 100 pages. It is divided into seven sections by a cut-in marginal index, headed: Algebra, Trigonometry, Analytical Geometry, Differential Calculus, Integral Calculus, Theoretical Mechanics, and Mechanics of Materials.

The few pages allowed to Algebra give condensed formulas and solutions in Exponents and Logarithms, Quadratic Equations, Proportion, Progression, Series, etc., for the refreshment of the memory.

Trigonometry takes up about six pages in presenting mathematical expressions for the trigonometrical functions and their interrelations; phases of plane and spherical triangles, are presented by mathematical expressions and equations.

Analytical Geometry begins with the transformation of Coordinates, considers the equation of the straight line and the circle, gives the expression for the Parabola, the Ellipse, the Hyperbola, the Cycloid, the Spiral of various forms, and the Catenary, and follows with the mathematical expressions for various solids of revolution.

The subject of Differential and Integral Calculus occupy sixteen pages of expressions and equations for handy use.

The book concludes with 52 pages given to Theoretical Mechanics and Mechanics of Materials. This includes Notation, Statics, Center of Gravity, Moment of Inertia, Radius of Gyration and Dynamics, with diagrams to explain the condensed equations. Various tables much condensed are introduced in Mechanics of Materials, with other diagrams to illustrate equations pertaining to the subject, including stresses, formula for loaded beams of various kinds, etc.

A good index of three pages concludes this little handbook, which is not a treatise, but is a condensation of much matter to be found in the usual engineering text-books, and all put in such form as to be readily referred to by one who may have forgotten the mathematical expression needed to solve some question that may come up in practice.

The book impresses the reviewer as being a very handy one to have in one's pocket or on one's desk for ready reference. W.

Useful Information for Practical Men; compiled for E. I. Du Pont de Nemours Powder Co., Wilmington, Del., 1908. 4¼ by 6¾ ins., 216 pages. Leather bound. Price $1.00.

This book is very much of the same class as the earlier books issued by the larger steel works, engine builders, etc., containing much valuable information, but primarily intended to advertise the articles manufactured and for sale by the Company who issues it.

The book contains the usual and always convenient tables of Weights, Measures, Mensuration, Specific Gravity, Temperature, Trigonometrical Functions, etc. Chapters on Rock Drilling and Rock Crushing Machinery follow, with others on Earthwork, Cement, Mortar and Concrete, Masonry and Bricks; also, on Boilers, Pumps, Fans and Blowers, Hoisting Engines, Light Railways, Locomotives, Iron and Steel, with tables of Weights of Sections, and Pipes, Wire, Rope and Chains for transmission, etc., followed with a section on Belting, Wood, with the strength of Beams, and with another section on Roofs, Covering, etc. Some ten pages give good information on "First Aid to the Injured" from various causes. Then, of more especial interest to possible users of explosives, is a section describing various explosives; the use and the precautions to be observed when using them. Also, when and how explosives may be used to advantage, the care of dynamite and black powder and precautions as to their use. A useful addition is a pocket inside the back cover and the introduction of a neat little note book of 48 pages made up of cross-section paper for the use of the owner in writing down his own notes, memorandums, etc., such as the owner of such a book might wish to preserve for future reference.

To one engaged in general construction work, quarry work, mining, etc., such a handy little volume, with all that it contains, should be of considerable value, though it is not intended to take the place of Trautwine, Haswell or Kent. It is well worth the price. W.

Design of Typical Steel Railway Bridges. By W. Chase Thomson, Asst. Engr., Dominion Bridge Co., Ltd., Montreal. 8 vo.; 6½ by 9¼ ins.; pp. 178; 21 figures; cloth. Price $2.00. New York, Engineering News Pub. Co., 1908.

This book is published as "An Elementary Course for Engineering Students and Draftsmen" and, like a previous work by the author under the title: "Bridge and Structural Design" was developed from a series of lectures given

by him under the auspices of The Dominion Bridge Co. Its purpose is to illustrate, by actual process, the steps and methods used in the complete design of some of the common types of railway bridges.

Six of these types are treated of in the order as named:

A 60 ft. Deck plate girder span.
A 100 ft. Deck Warren girder span.
A 150 ft. Through Pratt truss span.
A 200 ft. Through Pratt truss span with curved top chord.
A 170 ft. swing bridge.
A railway viaduct.
All of these are riveted structures.

The introductory chapter is devoted to extracts from the "*Dominion Government specifications of* 1901 *for steel railway bridges,*" which are used mainly throughout the work, and to a brief discussion of some of the provisions therein, notably those for impact stresses. It also describes the method of constructing the moment diagram which is made use of very largely in the determination of wheel load stresses.

A chapter is given to each of the structures above mentioned, in which the stresses of various kinds are determined. The members are proportioned and the details worked out to conform to the specifications; all in a concise, yet clear and comprehensive manner. An excellent feature in connection with the discussion of each structure is the detailed estimate of the weights of the members composing it, showing the methods of making these estimates in the office.

The design of the swing bridge includes that of the turning and end lift machinery and also the calculations for deflection and camber.

The author devotes a short chapter to the mention and description of additional types of bridges, not treated in detail. It is to be regretted that, of these, a pin connected span of medium length was not included among those whose design is worked out in full.

The last chapter is a discussion of the very live subject with bridge designers at present: "The latticing of compression members." While the treatment given this subject is of great interest and timely in itself, it would seem to the reviewer to be hardly within the scope of this book and, in his opinion the space taken by it might with more general value, have been devoted to the consideration of the pin span alluded to above.

The book presupposes a familiarity with the fundamentals of statics and structural mechanics. It will be found of especial value to the young bridge draughtsman and designer of limited practical experience. It should not be accepted by him, however, as an exponent infallible of the best practice in bridge design in this country, inasmuch as some of the designs worked out contain features which would not be used in R. R. bridges by our leading bridge engineers. As for example the $\frac{5}{16}$ metal in stiffeners, laterals, etc.

H. M. M.

The Metallurgy of Iron and Steel, by Bradley Stoughton, Ph. B., B. S., School of Mines, Columbia University, New York. Published by the Hill Pub. Co., New York. 1908. Cloth, 6 by 9½ ins., 509 pages, including a full index of 19 pages and with 311 illustrations, line and half-tone engravings through the text. Price $3.00.

This book is full of illustrations, contains many tables, and the chemical expressions indicating the changes that have taken place are introduced through the text to render more clear the reactions that are described. The text is generally easy reading and full of interest to those at all conversant with the Iron and Steel Industry. It will recall the various operations the reader may have seen at one or another iron works that has been visited. It is a book also for the student as it will give him a generally comprehensive knowledge of the various branches of manufacture of iron and steel. Yet as is to be

expected in the first edition of a new work, there are some errors to be eliminated in subsequent editions, and which should be pointed out to the student.

The book as a modern publication is now much more valuable than the one-time classic work of John Percy of over forty years ago. The treatise is not sufficiently exact and detailed to be of much value to a working metallurgical engineer, but to engineers in general practice the book will give a fairly good general knowledge of the various processes in the manufacture of the differet grades and varieties of iron and steel. The account of the Bessemer process—whether acid or basic—is good, though it would have been better, the reviewer thinks, had the fnudamental principles of this process been more fully developed, giving the *why* of the acid or basic process, with the advantages and limitations of each. The former is more general in the United States and England, while the latter process has been most fully developed on the continent, particularly in Germany.

The subject of the Foundry with the manufacture of cast iron or cast steel articles, the moulds, the melting and casting of the metals, is good as far as it goes, but is not as full and complete as the works of West, Bolland and Keep.

Of recent years great advance has been made in the study of the compositions of iron and steel by the aid of the microscope and in this book a good general knowledge is given as to the preparation and etching of specimens for examination. The character of the metal of steel rails, the presence of slag and blow holes is frequently investigated by a modification of the above by preparing a cross section of the rail, by reducing to a plane surface and polishing and then etching the surface, which will give in relief the uniformity (or reverse) of the metal. An ink impression of this relief etching can be taken on paper which will show clearly the presence of impurities or cavities in the rolled rail.

The book contains much more of valuable matter than has been noted in the preceding, as it is quite full of information along all the lines of the metallurgy of iron and steel, and is a welcome addition to the library of the engineer. A very useful and interesting part of the book is the Bibliography of the subject printed at the end of the respective sections, which will aid one to get further information on any one particular subject. This feature is most commendable.

W

TECHNOLOGICAL DICTIONARY IN FRENCH, GERMAN AND ENGLISH. Edited by Alexander Tolhausen, Ph. D. Revised by Louis Tolhausen. Fifth Edition with supplements. The Macmillan Company. Three volumes, $2.75 a volume.

For the information of those who are not acquainted with this excellent reference book which has lately been added to the library of the Society it may be said that it is a dictionary of technological words, French, English and German, in which the more common technical terms of each of the three languages are given their equivalents in the other two languages. The work is in three volumes, of approximately a thousand pages each, including the supplements, volume one translating the French into English and German, volume two the English into German and French and volume three the German into English and French. The dictionary treats of the terminology of some two hundred or more technological arts. The original edition appeared in 1877 and since then the work has been several times revised and enlarged so as to keep it up to date. Each volume of the present edition has a supplement of the more recent terms, particularly in Electricity, Telegraphy and Telephony.

It is of course impossible, or next to impossible, to compile a dictionary of technical words and expressions which will be complete and entirely satisfactory. The technological terminology of almost every art, is in a state of charge and of development just as are the scientific theories and principles which underly it. The immense increase within the last few years of scientific terms and of words of industrial art would make completeness or very

close definition an impossibility within the compass of three thousand pages. Neither one nor the other has been attempted. As the author states in the French preface to the first edition the object of the dictionary is to give for the principal technical words of each of the languages as wide a range of synonyms in the other two languages as possible, leaving to the user to select the particular equivalent which best fits the occasion. This object is admirably accomplished and within its limits the dictionary is remarkably full and accurate. For a person who has occasion to read or translate into English, French or German technical literature it is indespensible. P. H. T.

PRINCIPLES OF DIRECT-CURRENT ELECTRICAL ENGINEERING, by James R. Barr—A. M. I. E. E.—Whittaker & Co., London—The Macmillan Co., New York—Cloth—6 by 9 inches, VIII, 551 pp., including index; 294 illustrations, including some folding plates. Price, $3.25 net.

The author, in his preface, states that his object has been to present a text-book presenting the principles of electrical engineering to students who have a practical knowledge of the fundamental principles of electrical physics and mathematics.

The first chapter in the book deals entirely with definitions of the fundamental electrical and magnetic units. Brief and concise definitions of the different units are given, and frequently suitable analogies and problems are given, with the object of clearly illustrating their applications in practical work. In some instances tables and curves are given, showing the electrical and magnetic properties of certain materials as relating to the particular unit under discussion. Mathematical explanations and proofs are given when it has appeared advisable to illustrate the relation between certain important units. However, in no case are the mathematics intricate.

The subject of electro-magnetism and the magnetization of iron is dealt with in a concise manner. The important principles and laws are presented sufficiently in detail to be applied to the discussion later in the book relating to the design and characteristics of dynamo-electric machines. This is done, however, without going into intricate theories and details. A brief description of a few of the commercial methods of testing iron is given, with instructions and problems sufficient to show their application.

A chapter is given to the subject of electrical measurements, describing representative instruments of each and a few of the types in commercial service. In one or two instances calculations are given of the dimensions of the instruments, so as to give an insight into the methods of designing for special services.

A brief history is given of the development of the storage battery. The elementary chemical actions due to charging and discharging are followed through, and the chemical and electrical conditions before and after charging are carefully described. Some discussion is given to the performance and operating of batteries, together with a description of certain constructional details of battery installations.

Electric illumination is given a practical treatment in one chapter. The different standards of illumination and the different commercial types of lamps are described and illustrated. Calculations and problems are given, showing the practical methods of calculating the illumination and efficiency of lamps. A short space is devoted to explaining the most economic efficiency of different types of lamps under specified conditions.

The subject of direct-current transmission receives considerable attention. The requirements and specifications of transmission lines are mentioned in detail, and there is a sufficient description of constructional details to give a fairly good idea of these features. The author then begins the description of the mechanical and electrical details of dynamo-electric machinery. Calculations of several machines are carried through, illustrating dynamo design. Several examples of machines for different classes of service are described. The author emphasizes the importance of suitable commutation devices for

modern high-speed, turbo-driven generators. Several methods of applying these commutation devices are given. The more important criteria of dynamo design, particularly that applied to the design of high-speed, turbo-generators, also.

The commercial methods of testing machines for characteristic curves and efficiencies are explained and described, with a number of curves as examples of actual results obtained. Methods of operating dynamos and motors are described and illustrated with wiring diagrams.

Auxiliary devices, such as rheostats, controllers, switches, relays, etc., are described as to mechanical and electrical details. Their requirements and limitations are discussed, and the method of selection of certain types for special services is explained.

The author has been careful to give the fundamentals of electrical physics, which is advisable in text-books for engineering colleges. The frequent use of practical problems is always advisable in text-books of this character, to insure a thorough understanding of the subjects under discussion.

In the earlier portion of the book the author has thoroughly carried out his idea of presenting and illustrating the principles of direct-current engineering. In the latter portion of the book perhaps the author has put rather too much emphasis upon the design and testing of dynamos, but whatever there is upon that subject is well presented and complete enough for general reference purposes. The general purpose of the author has been adhered to for the most part, but it would seem that if a corresponding space had been devoted to the subjects discussed previous to "Machine Design and Testing," the book would have been more representative. The subject of storage batteries is important enough to require a more thorough treatment, as also the subject of underground conductors. The methods of designing an underground system should have been presented in more detail and illustrated with calculations of feeder and main networks. Telephony and telegraphy have received no mention, possibly for the reason that they were not considered as coming within the scope of the title. Very little space was devoted to station or system design, and practically no mention was made of economic conditions affecting their design. However, in general the book is filled with excellent information. What material there is upon the subjects has been well presented, and the subjects are in logical sequence. The book should find a valuable place as a college text-book. E. F. S.

REINFORCED CONCRETES. A Manual of Practice. By Ernest McCullough, C. E. 1908. Chicago. Cement Era Publishing Co. Cloth, 5 by 7¾ ins.; 128 pages; illustrations and tables. Price $1.00.

This book is in eight chapters, as follows: Strength of Beams; Loads on Beams; Columns; Walls, Tanks and Footings; Design and Cost; Forms; The Conduct of Work; Tools.

The first four chapters treat the subjects in a theoretical manner, giving formulas and tables to be used in design. The chapter on Design and Cost is short but contains valuable data. The remaining three chapters relate to construction and contain much practical information gleaned from the author's wide experience in the field. In Design, the straight line formula has been used throughout, in order that the book might conform to the building ordinances of the various cities of the United States.

On the whole, the book is well worth the price asked for it, as it contains in compact form a mass of valuable information which it would require years of experience to learn. L. A. W.

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K. B. MILLER....................................2 years
E. N. Lake................... ... .3 years
Members of Executive Committee.

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Regular Meeting—1st Wednesday evening of each month except January July and August.

Extra Meeting—3rd Wednesday evening of each month except July and August.

Electrical Section—D. W. Roper, Chairman, generally the 2d Friday of the month, October to May, inclusive.

Board of Direction—The Tuesday preceding the 1st Wednesday of each month

NOTICE

From the dues of each member, $2.00 is set aside as a subscription to the JOURNAL.

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STEEL RAILS FOR PRESENT SERVICE: THEIR MANUFACTURE AND THEIR FAILURES.

By Dr. P. H. Dudley, N. Y. Central R. R. Co.

Presented May 18, 1908

It was a quarter of a century last April (1908) since I completed and submitted to the New York Central and Hudson River Railroad Company, the design for the first 5 in. 80 lb. steel rail for service in the United States. My track inspection mechanism had been in service four years and as complete as at present for two years. I had taken several thousand miles of diagrams of the surface undulations in the track, with a large number of sections of rails ranging from 52 to 67 lbs. per yard and from $3\frac{1}{2}$ to $4\frac{1}{2}$ inches in height. I had made repeated inspections over the tracks of the Philadelphia, Wilmington and Baltimore, the Boston and Albany, and the New York Central and Hudson River railroads. I had also run over the tracks of the Boston and Maine, Eastern, Lake Shore and Michigan Southern, Baltimore and Potomac, and portions of the Pennsylvania railroads.

The autographic diagrams on a scale of one inch in length of paper to fifty feet of track with the surface—vertical—undulations full size, indicated the action and behavior of the various sections under the wheel loads of the mechanism of all the important foreign and American brands of rails. The finish of each was different, and in a short time I could recognize the principal brands from the diagrams, as we passed over the track. The data collected for analysis and interpretation of facts, from the different sections and railroads, included a great range of conditions of operation and maintenance and was of more value than could have been obtained from a single railroad. It soon become evident from the diagrams and the figures of the combined mechanism for summing the undulations into feet and inches per mile, what the trackmen could do with the sections in the track and quite as important what were their limitations. Railroad officials expected at first on those portions of the track which were found below the standard desired, that more labor, ballast or cross-ties would correct the deficiencies and render the entire track uniform per mile.

Repeated inspections after such improvements by labor and material, without change of rails, still gave evidence of characteristic conditions of the steel per mile and while the general track was improved by the higher standard of maintenance, those features pertaining to the steel and sections were not eliminated. This was a new fact for consideration and elicited extended discussion.

I recall reporting to a Railroad President, who was interested in the track inspections and investigations, that the instruments indicated a few miles of new rails laid the preceding year, had minute waves in the surface, but which he considered hardly probable. He said, however, "if you can prove that you have interpreted the indications correctly, I will have the rails replaced." A steel straight edge confirmed the character of the indications, and it was necessary only to make plaster casts of the surface of portions of a few rails, which he could have in his office for examination, to convince him that the interpretations were reliable.

The rails were replaced by those having a smoother finish with decided improvement in the surface and riding of the track. The early steel sections out-wore six to ten of the iron rails they replaced and enabled the railroad companies to reduce the excessive cost of operation and maintenance incident to the daily breakage and failures of the iron rails. The cost per ton of the steel rails contributed to the retention of the limber sections in the track which permitted the concentration of the major portion of each wheel load in passing to every successive cross-tie, the latter abrading and crushing under the rail seats.

The fishing depths of the sections were low and inadequate, the joint fastenings inefficient, and the rails in a short time acquired permanent sets in the tracks which I classified under three principal forms.

The First Form was where the joints were low and the centers high.

The Second Form, the joints and centers were low and the quarters high.

The Third Form, the surface was a series of short waves called "kinkey" by the trackmen.

There were often combinations of the First and Third, and of the Second and Third. The static wheel loads were augmented by the wheel effects—dynamic shocks—once or twice what they should have been, incident to the low joints and irregular surface of the rails with a consequent high train resistance.

The driving wheel loads had increased but little upon the light steel rails, over the practice upon the iron sections. The expended tractive effort had been augmented a few per cent in the American 8 wheel locomotives, but the steam generating capacity was inadequate for the essential requirements of through express trains. Moguls and consolidation locomotives were being used for freight service on lines with heavy gradients.

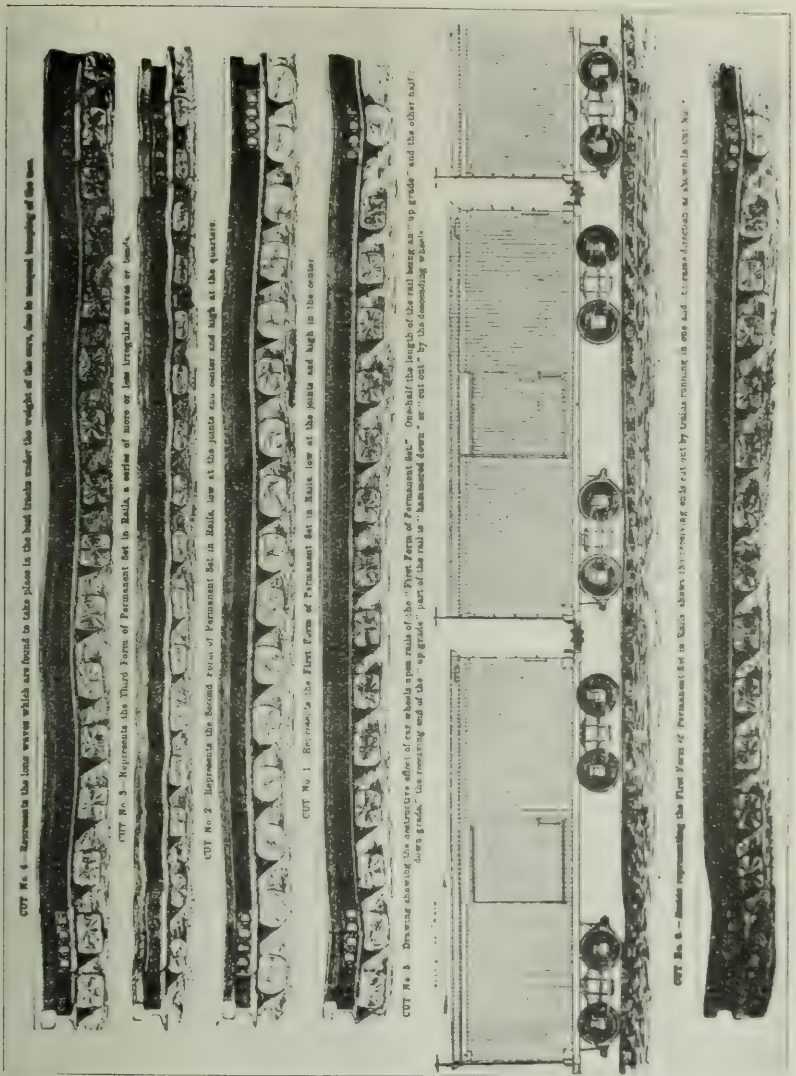


FIG. 1.

Different forms of Permanent sets in light rails.

The light steel rails did not admit sufficient driving wheel loads, combined with the effect of the expended tractive effort to permit the progress in transportation that a country of vast extent of territory required for its development.

It was not alone weight, but augmented mechanical properties of a rail section in the track which would allow the development desired. The road beds were of ample strength to double or treble their tonnage provided the moving wheel loads were distributed in passing to a longer portion and greater area of the road bed. The stiffer rails would relieve each individual cross-tie of as great weight as it received under the lighter rails by distributing a greater percentage in the wheel spacing.

Railway officials riding in my Track Indicator Car, became convinced that the most economical way to increase the stability and capacity of their tracks was to replace their light and limber sections with rails possessing greater mechanical properties, of stiffness and strength.

Officials who did not ride over their tracks in my car were equally as positive that the increased cost of the proposed heavier section would be greater than the benefits to be derived. Good and sound criticism is the most valuable aid a worthy project can have. I was able to point out the fallacies of each criticism to the satisfaction of the New York Central officials who would be directly responsible for the installation of the stiffer section. A 5 in. 80 lb. rail requiring only 23 per cent. more of metal to secure a gain of 66 per cent. in stiffness and 40 per cent. in strength over the former 65 lb. rail was a valuable and economical engineering structure, to increase the stability and capacity of the track. The most optimistic estimates of the benefits of the stiffer rails in the track were less than the realized results, in the progress of transportations.

The 5 in. 80 lb. section was rolled in April, 1884, and laid in the tracks the following July. Mr. J. D. Hawks, Chief Engineer of the Michigan Central R. R., made a 5 in. 80 lb. section which was put in service in 1886. President Roberts of the Pennsylvania Railroad, riding over the 5 in. 80 lb. rail on the New York Central R. R., observed and inquired what it was, and ordered his engineers to design a 5 in. 85 lb. section for their service. The former round topped $4\frac{1}{2}$ inch sections had given the trackmen so much trouble in rolling out and spreading the gage, that it required the cross-ties to be adzed and the rails rolled in, each winter, and they were positive that the 5 in. rails could not be held in the track.

My explanations to the supervisors was, that I had considered that feature and had made the head broad, with a 12 in. top radius, to make the passing wheel treads hold the rails in vertical position, was hardly credited until after thorough trial. When the supervisors found that their tracks with the broad topped, stiff rails kept the gage even without braces on the curves, and also remained in surface for a longer time than the former $4\frac{1}{2}$ in. rails, they saw they were being encouraged and aided in their efforts to secure high standards of track.

The stiff and stable track with the 5 in. 80 lb. rails, enabled Mr.

Wm. Buchanan in 1889 to design the first 100 ton passenger locomotive for service in the railway world. It commenced to run in April, 1890, and Nov. 30, 1891, the "Empire State Express" was installed, the educator for high speed trains for all railway countries. The activity and development of the use of stiff sections of rails, in the meantime, had been great, for American railway officials are quick to perceive and apply principles which achieve results. In 1892 the first 100-ton locomotive started its high speed runs on the first 100-lb. rails.

The stiff sections of rails, as girders, have permitted a development of locomotives until those of 125, 150 and even 160 tons weight, with an equivalent increase of tractive power are common. The freight car capacity also, has increased from 10 to 50 tons, while the freight train load, according to the topographical features of the lines, has been augmented four to six times in tonnage.

FIG. 2.

B. & A. R. R.—95 lb. rail of 0.60% Carbon and 0.06% Phosphorus.—"Bethlehem," 1891—16 years' service under heavy traffic. Some segregation of the Carbon, indicated. A good rail.

The work the metal must do on the bearing surface to receive, carry and then distribute the heavier wheel loads through the section to the cross-ties, ballast and road bed, is of necessity greater than occurred in the light and limber sections. The bending moments are greater but with less deflection of the rails, cross-ties, ballast and road bed. The records of my work in the past show that I recognized the necessity of increasing the physical properties of

the metal, as the mechanical properties of the sections were augmented, and from 1890 to 1900 I made over 600,000 tons of rails of 0.60%, or over, in carbon, according to the section, the phosphorus being confined to 0.06%, or under.

The work that I was able to do between the dates mentioned when cupola-metal was used for steel making and care taken in the composition, shows by actual experience in the track, that sound ingots have been made in which piping is the least of their defects. This can be repeated in larger ingots with the advance in metallurgical knowledge of today.

I made 95 lb. high-carbon, low phosphorous rails from 14 in. ingots at the Bethlehem Steel Co.'s Works for the Boston & Albany R. R. in 1891 and 1892, and gave 5 to 6 min. in the ladle for the oxidation products to escape from the chemical reactions of the recarburizer. The 75 lb. rails for Dr. Webb's Mohawk and Malone railroad were also made at the same time. Those high-carbon, low-phosphorous rails were rolled while Mr. John Fritz was General Superintendent of the plant, for he was the only manufacturer who admitted at that time that such rails could be made. These were premium rails, and the late Mr. William Bliss, President of the Boston & Albany R. R. paid $2 per ton additional for the high grade of steel, and Dr. Webb also paid the same premium for part of his rails. Mr. Bliss considered it economical to secure as good material in his rails as possible, and their services after 17 years, most of them being still in the track, has proven the wisdom of the undertaking.

Prior to this time Mr. Fritz had constructed his 48 in. blooming-train for 16 in. and larger ingots, but it cracked the skin of the ingots so much more than the former 26 in. blooming-train, that as I had my choice of which size of ingots to use, I chose the 14 in. ingot, which made 2 lengths of 30 ft. rails, while the 16 in. ingots made 3 lengths of rails.

The Boston & Albany rails were of 0.60% in carbon and down to 0.06% in phosphorus, as were also a part of the Mohawk & Malone rails. The molten steel after being recarburized in the converter, was poured and remained in the ladle from 5 to 6 minutes, to allow the chemical reactions and oxidation-products to escape, before teeming the ingots; these were stripped, then thrown down in the pits and charged into horizontal furnaces for equalizing the heat before blooming. The 26 in., 3-high blooming-train of 11 passes was used, and the blooms were cropped until sound steel was obtained, then chipped under the steam hammer, and again charged into horizontal furnaces for reheating and then rolled in 11 passes into rails. They were finished between 950 deg. C. and 1,000 deg. C., as nearly as could be measured by the Siemens copper ball and water pyrometer. We had not then advanced to the scientific requirements of sawing the rails 0.01 in. shorter for each second of time after leaving the roll and rolling so cold as to frequently damage the rail as a girder. Rolling the rail cold, for wear, is one factor to be considered, but

this in any case must not exceed the safety-factor as a girder. The new type of rail sections with 0.5 in. thickness of edge can be rolled too cold for safety, as had occurred in some experiments. The Bethlehem rails, on the Boston & Albany R. R., after 16 and 17 years' service on heavy grades and sharp curvatures, have lost only about 1/8 in. in height, from the large volume of traffic which has passed over them. These rails were not lettered to show from which part of the ingot they came, but walking over the track it can be readily seen which were the rails from the top of the ingots. The fractures of these rails, both on the Boston & Albany and the Mo-

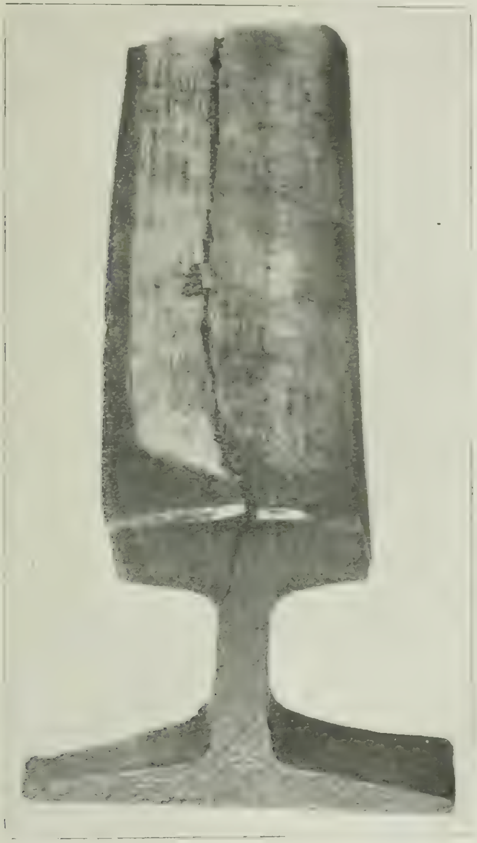


FIG. 3.

B. & A. R. R.—95 lb. rail, Bethlehem, 1891.—Failed Jan., 1908. Supported at joint by 20 in. angle bars of 0.10% Carbon, which were soft and wore rapidly. The rail head flattened and split from insufficient support, rather than from inferior metal.

hawk & Malone railroads have been exceedingly light after so many years of service. They have excellent wearing properties and are also tough as girders.

More than 600,000 tons of rails of my sections were rolled at Scranton, Pa., with carbon of 0.60% and phosphorus of 0.06%. These were rolled from 14 in. ingots of sufficient length for three—30 ft. rails. Special efforts were made to secure a composition which would set well in the ingots and be free from pipes. The number of "stickers" which were broken under the drop were sufficient to show the general soundness of the ingots.

DEFECTS OF INGOT STRUCTURE.

Pipes, as shrinkage cavities or from slag inclusions from the recarburizer, or from vessel slag which accidentally gets into the ingot molds, are well known facts, though pipes due to shrinkage cavities are best known.

Minute blow holes often occur in the sides of the ingots and frequently are numerous in the central core. The latter are generally surrounded by segregated elements of carbon, phosphorus, sulphur and silicon.

The chemical composition should serve two important functions:

1st, to provide the basis for the physical properties desired in the steel.

2nd, to secure sound ingots. This requires the adjustable feature of the composition used in making the high carbon and low phosphorous rails.

The exhaustion of the low phosphorous ores requires the use of phosphorus at 0.10% and the carbon for 100 lb. rails for service where the temperature falls to 20 or 30 degrees below zero Fah. should not exceed 0.45 or 0.50%. The silicon can be from 0.10 to 0.15% with the manganese at about 1% for ingots of a length of about 2½ times the width of base. Sound ingots can be made by holding the steel after recarburizing in the converter, 2½ to 3 minutes or about the same time in an intermediate ladle before teeming. The latter has been the practice at the Illinois Steel Co., South Works, for some years and the benefits are well established. The nozzle in the ladle should not exceed 1½ in. or at most 2 in. in diameter, and the metal be poured in a solid stream, to avoid spattering the molds, and carrying quantities of air in with the steel.

The columnar structure in the corners of the upper part of the ingot will entrain traces of slag and gas which will appear as defects in the heads of the rails after more or less service. The upper part of the ingot will have a well defined central core inside the columnar structure of the ingot.

To study the defects of ingot structures besides those due to pipes, I commenced lettering the rails A, B, and C, as rolled from the top, middle and bottom of the ingot for the New York Central

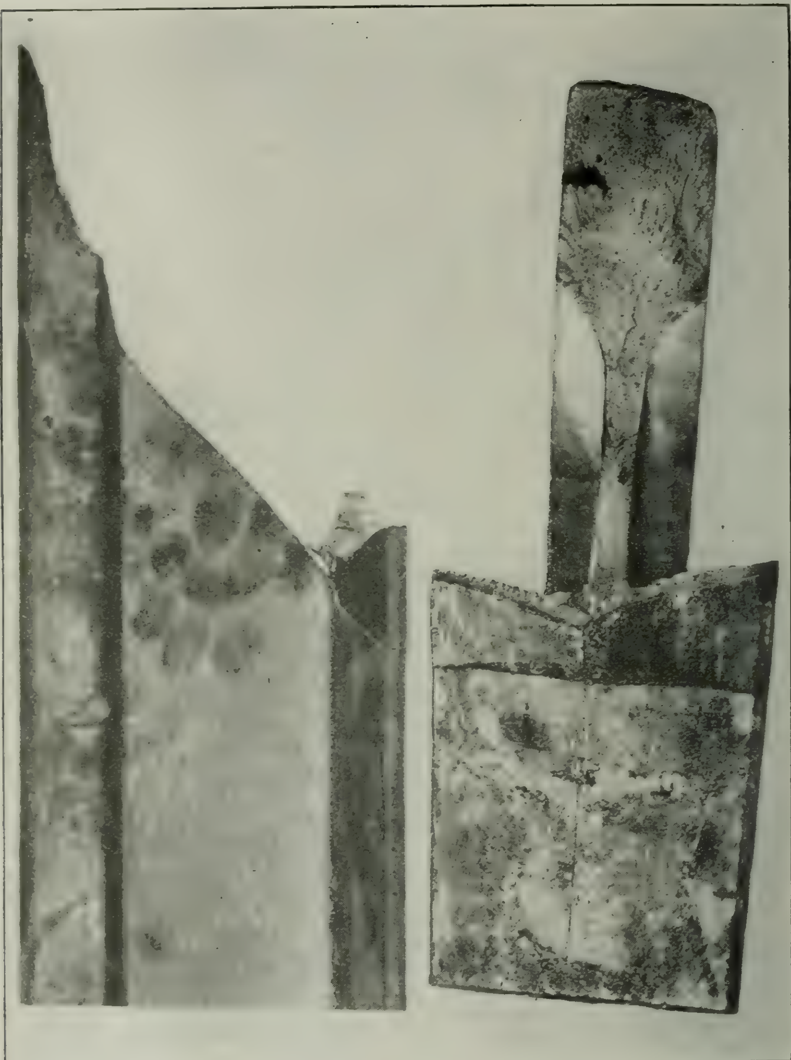
and the Boston and Albany railroad companies in December, 1892, at the Lackawanna Iron & Steel Co.'s plant, Scranton, Pa. The rails contained 0.06% in phosphorus and 0.55 to 0.60% in carbon for 80 lb. rails and 0.60 to 0.70% carbon for 95 and 100 lb. rails. These rails after 12 to 16 years' service have developed but comparatively few base fractures, which were nearly equally divided between the letters. Out of over 500,000 tons, only 20 piped rails, in the webs and heads, have been found to date, though there is about one-fourth of one per cent. of split heads, which are common to all of the letters. There is a slightly greater percentage of defective rails in the letter A than in either the B or C rails. These rails were all made from ingots which were cast in the pits and as soon as they were stripped, thrown down into a horizontal position, then loaded upon the ingot trucks and charged into horizontal heating furnaces. The chemical composition was adjusted to make a sound ingot, the metal carrying from 0.6 to 0.8% of copper. Many of the ingots as "stickers" were broken under the drop to see the solidity of the metal, and it was rare to find a central cavity of 1/8 in. in diameter in any of the ingots after they were cold. The rails are giving a slow rate of wear and only near the inside running edge of the upper corner of the head of the A rail, for about one-third of its length, do they show the slight inclusions of gas or slag in the structure of the upper part of the ingot.

The B and C rails rarely show any defects. The letters can be found on most of those now in the track. The "New York Central Lines" have been restencilling a number of rails with white paint, indicating by the letter so that persons can examine them and see the different rates of wear between the A, B and C rails. The A rail usually wears slightly faster than the B or C. Rails which have been in service 16 to 17 years and have carried from two hundred and two hundred fifty millions of heavy tonnage, have lost only from 1-16 to 1-8 of an inch in height in the center of the head, while those on the curves show but little flange wear. The effort in making those rails was to secure a slow rate of wear by a chemical composition and not by cold rolling, as is proposed at the present time. But few half-moon breaks in the base have occurred in these rails after their long service.

COLD ROLLING.

It is not generally understood that steel for rails, can be rolled too cold during their manufacture. It is found by experience that cold rolled rails, which have been manufactured extensively since 1900, break to a greater extent in the tracks when the temperature falls to zero or below, than the rails which were rolled at the ordinary working temperatures. The cold rolling is beneficial for the rate of wear in the head, but when the rails are rolled at near or below the "critical temperature" for the steel, it is detrimental to the rail as a girder. The base, web and head may be chilled and

hardened so that the ductility is decreased, for the ordinary chemical composition of the section, and they are injured under the straightening press.



FIGS. 4 AND 5.

Shear over the supports of Drop Testing Machine. Under the drop test, the shear is usually curved or inclined and more than in the track. The two triangular fractures in the base of rail are due to reversing the bending of the edges as occurs under the gags of the straightening press.

The half-moon breaks, which have occurred over the cross-ties in the rails of the past four or five years manufacture, are generally associated with cracks or seams in the base. These may be due to cracks in the skin of the ingot in blooming, inclusions of silicates of manganese, or laps from the passes, or ragging. Many consider that these are the primary causes of the fractures. The more recent physical examinations of broken rails show, that associated with these seams, the metal is usually brittle, having been chilled in rolling. The flange cracks easily under a light blow of the sledge. The fractures can in many cases be traced directly to the initial strains in the metal due to "gagging" in straightening the rail at the time of manufacture. The edge of the base of the rail on one side will check from the bottom upwards, and in an inch or two from that, the top of the flange may check from the top downward.

These are detailed progressive fractures even though completed under a locomotive or train, and usually when found some part of the fracture had previously oxidized or discolored, showing it had been days, weeks and sometimes months in developing.

The gagging in such cases was sufficiently severe to put reversed bends in the edge of the base and had left decided initial stresses in the metal at the junction of the base and web and in the flanges due to permanent sets of the metal in straightening the rails. The majority of the half-moon or crescent shaped fractures occur on the top of the cross-ties, and finally rising through the web and head, as a vertical shear with slight curvature through the web. Comparing these fractures with those which occur over the supports of the drop testing machine, they are found to be identical except as to the length of the curve, as the rail shears over the support. Increasing the thickness of the base for colder rolling than has been before considered permissible, does not check the tendency of the metal to fracture in the edges of the base under the reversed strains of the gagging process. The cold rolling reduces the ductility, the same as though greater additions were made of carbon or phosphorus. The fractures in the base of the cold rolled rails are not confined to the letter A, representing the top of the ingot, as is generally understood, but are distributed through the entire rails of the ingot and in a few cases have been identified as confined to a single ingot of the heat. Out of 201 specimens of broken rails, 43 were A, 46 B, 33 C, and 18 D rails. The latter form the smallest percentage of any of the letters in the track, for the reason that in long ingots they generally make the most seconds and are rejected as second-class rails. There were 61 rails out of 201 specimens in which the letter had become so oxidized as to prevent identification. The A rails formed about 21 per cent. of the letters identified, the B 22 per cent, the C 18 per cent, and the D about 9 per cent.

The base failures I have described are those of my observation under high speed trains where the temperatures were 20 to 30 de-

grees below zero Fah. for several consecutive days. The winter of 1906 and 1907 had the longest protracted periods of low temperatures, in many localities that the weather bureau has yet recorded, and I did not see more than one or two direct tension breaks, all of the fractures being developments of injuries, strains or defects in manufacture, coincident with the combined cold and heavy service. These are technical problems for the rolling mills and the railroads to investigate and solve.

The low temperature has two effects upon the ordinary Bessemer steel rails: First, to raise the elastic limit and increase its fragility under shocks. Second, to set up thermal stresses due to contraction before the ends of the rails slip in the splice bars.

Each fall in temperature of one degree Fah. sets up a stress of 200 lbs. per square in. of the area of the section where the ends of the rails are held firm. The friction of the splice bars per lineal in. of the 80 lb. rail of my sections, is 4300 to 4400 lbs., and for the 100 lb. splice bars it is 4800 to 5000 lbs. One-half of a 36 in. 80 lb. splice bar would hold a tension of 77000 lbs., and the 100 lb. splice bar 86000 lbs. before the ends might slip in the splice bars. The most frequent base breakages are in the periods of low temperatures, and consequently affect the rails laid in cold, more than in warm climates.

HEAD FAILURES.

The numerous split heads in rails of recent years, called by the trackmen "piped rails" and which are found in all brands, occur more in some than in others. When the steel is cast in long ingots, the upper part is not deoxidized as much as the average, and with a well defined exterior envelope not securely connected to the spongy central core. The passing wheel loads cause the metal in the bearing surface to spread laterally and it becomes loosened from the central core underneath. The widening layer of metal eventually checks and splits that of the central core underneath. The surfaces of the vertical split discolor in a short time and are often reported by the trackmen as a flaw or pipe.

There are often one or more minute layers of ladle slag—(silicates of manganese) from the chemical reactions of the recarburizer, 1/8 to [illegible] of an in. under the bearing surface, which permits the metal to spread easily and split the metal underneath, particularly when there are small seams formed by the closing and elongating of small gas bubbles surrounded by segregated metal. The split may develop at the end, but more often occurs in one or two places in the quarters or centers of the rails. It sometimes starts and breaks from one side of the head and develops toward the center and then across to the opposite side.

The spattering of the mold in pouring or when a heat must be pricked, seems responsible for some split heads; but the teeming of the ingots too quickly after recarburizing the steel, containing minute

globules of silicate of manganese associated with insufficient deoxidized metal, seems to be a greater factor.

FIG. 6.

N. Y. C. & H. R. R. R.—100 lb. Carnegie rail of 0.45% Carbon and 0.10% Phosphorus.—Split head. Segregated fragile metal forming central core. The envelope of metal, forming the bearing surface for the head is soft, and has the usual expanding wedge over the vertical split in the central core.

The central core of the upper part of the ingot is often a motley collection of segregates in the insufficient deoxidized metal which were rejected by the setting steel of the lower portions of the ingot and entrained before rising to the top. Some of the segregates, as ovoid bodies in the ingots, are drawn out in rolling into long cylinders and form the dark streaks in longitudinal etchings of the rails, while the white streaks are generally carbonless iron. The silicates of manganese as globules, are drawn out into threads in the section of the rails, resulting in a reduction of the solid volume in the heads, particularly when associated with insufficient deoxidized metal. The rapid wear, flow of metal and crushing of the rail ends, are to be expected from such conditions.

Pipes in ingots from shrinkage cavities or inclusions of ladle slag or vessel slag, ganister and split heads, would be "pipes" to the trackmen, but each require a different metallurgical treatment for correction.

FIG. 7.

100 lb. rail—A. S. C. E. section showing accidental inclusion of ganister. The result in manufacture, or in the track, would be reported as a piped rail, while true in effect it is not due to the shrinkage cavity of the ingot. Its prevention is a mechanical, rather than metallurgical problem.

The consumer is expected to tell the manufacturer when the rails fail, which is but a small part of his privilege and duty; he must investigate and tell the manufacturer the reasons why they fail to meet the conditions of service. Transportation has made such rapid strides during the past two decades on the stiff rails as engineering structures and the demands of the commercial interests for more facilities, so pressing and insistent, that some things have been done to meet emergencies by both the consumer and manufacturer, obliging both to work nearer the upper margin of capacity than would otherwise have been done. Some manufacturers have shortened by one or two minutes the essential time after recarburizing the heats before teeming the ingots, while the consumer has been obliged to increase the wheel loads, expended tractive effort of the loco-

motives and speed of his trains to a degree only recently considered possible.

Two years ago to suggest to the manufacturer that slag was disseminated through the steel in the rail head, was met by what he considered just indignation as to the correctness of this statement, but when shown to him, he no longer doubts but takes measures for its elimination. The steel manufacturer has to contend with the storms quite as much as the rail user. The atmospheric moisture will not wash out or submerge the manufacturer's plant, but the

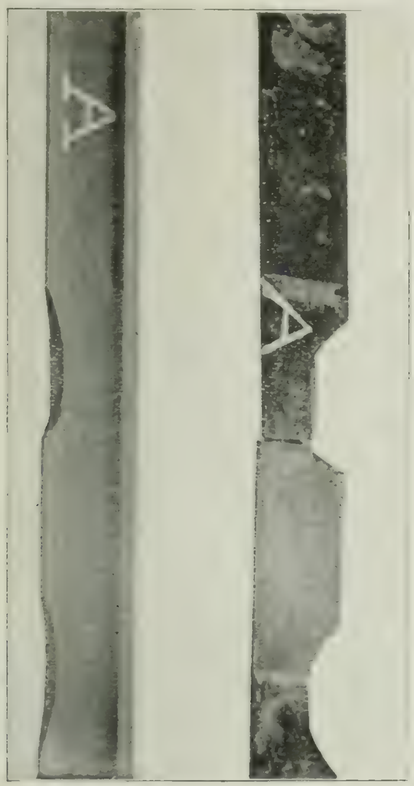


FIG. 8.

N. Y. C. & H. R. R. R.—100 lb. rail—L. S. Co.—1904. Two crescent shaped pieces broken from base of rail. The development of checks or strains under the straightening press in manufacture. One of these checks or strains contributed with seams of manufacture in the base, to its detailed fracture and shear of the remaining part of the section and is typical of rail breakages in cold climates. The check adjacent to the shear of the web started from the underside and also split near the median line of the base, while the opposite end is checked from the upper side of the base. The other crescent fracture checked from the underside of the base.

amount of moisture which in humid weather, will go into the blast furnace will change the character of the product.

The Bessemer converter uses for the conversion of each ton of metal, five to six-tenths of a ton of air, and whether each cubic foot of air contains one, or six to eight grains of moisture is felt at once in the Bessemer department and the rail mill by increased difficulties of manufacture, not easily surmounted.*

It is gratifying for me to find that from independent investigation that the consumer and manufacturer are arriving at the same facts and conclusions from which mutual benefits will result.

DISCUSSION.

Mr. W. H. Finley, M.W.S.E. (Chairman): In the matter of rails —taking the paper just as it was read by Dr. Dudley—I would ask if any better results are obtained by the use of the open-hearth process than have been secured in the past by the use of the Bessemer process?

Dr. Dudley: That is a matter which must be intelligently tried. We shall avoid, by the basic open-hearth process, as much prosphorus as we now have in our present rails, and probably the brittleness will be less, but so far as wear is concerned that is something which will have to be determined by service tests. The brittleness seems to be less in the basic open-hearth steel, unless it runs too high in the carbon or other hardening elements. The metal must be higher in the carbon to get a serviceable rail by the basic open-hearth process, than is necessary in the Bessemer process, with the use of 0.06% of phosphorus. I have seen a number of rails rolled of basic open-hearth steel in which the carbon ran from 0.65% to 0.75% and those rails were tough. However, with a slight increase in carbon running from 0.68% to 0.78%, in an ordinary section, a great deal of brittleness developed, and the rails were not as tough as those with a less amount of carbon.

I made for the New York Central R. R., a few thousand tons of basic open-hearth rails, rolled from three length ingots and branded A, B and C, commencing with the top of the ingot. All the different letters will be observed for wear. We are putting them in a place where we require great toughness. We will have more reliability, so far as brittleness is concerned, than in the ordinary Bessemer rail with 0.10% phosphorus.

Mr. Finley: I think Dr. Dudley ought to be able to give the railroad companies some information as to the road-bed itself. He has spoken in regard to the rail and the effect of the rolling stock on the rail. Doubtless he has observed, in his experience, how the road-bed, the ties, and ballast are affected. Can he suggest anything that would be of benefit to the railroad companies in that respect?

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*The "dry blast" was applied to the Bessemer Converter at the South Works—Illinois Steel Co.—a few days after this paper was read and with beneficial results. P. H. D.

Dr. Dudley: The observations which I have described in detail tonight—the road-bed and ballast—were factors which were taken into consideration. It is necessary to have a well-maintained road-bed, to get the best results so far as the undulations are concerned. The standard of maintenance has improved in the last decade and the tonnage carried is three or four times as great as it was ten years ago. Some of the railroads have 40 to 45 per cent. of the road-bed covered with cross-ties under the heavy rails, but I think such a high percentage is not necessary. There is considerable elasticity to the track and road-bed, which settles from 1/8 to 1/4 in. under wheel loads of the locomotives and cars. It is difficult to make that amount of undulation uniform, where stiff rails, with too many ties, are used per rail length. It is almost impossible, in the tests for the unit fibre strains, to get uniform results from the different axles even with the same static loads. We obtain uniform results when we compare the entire stresses from a locomotive or a car; for the single wheel there is wide variation, due to unequal distribution of the load, tamping and ballasting of the track. It is difficult for the trackman to tamp every tie so it will have a uniform bearing. The results show that as a rule, a track well ballasted with stone is maintained for the entire year in a better condition than a gravel-ballasted track, though the latter is easier to surface.

It often takes two years after it has been replaced by stone ballast, for the track to become as smooth as under the gravel ballast. The trackmen must learn how to take care of the track. Many are discouraged at first when replacing the gravel ballast with stone, but after they become experienced, they keep their track in much better condition. The first year or two after the change from gravel to stone ballast, the tracks are somewhat rough and do not ride smoothly. There is much in favor of stone ballast, however, for heavy service; the road-bed should be well drained, which is one of the most important factors; not as much attention has been paid to this as should be in this country. By draining, a firm road-bed is secured, in which the undulations will be uniform.

The breadth of the top of the rail is another important item; it makes a smoother track. The narrow top rail cuts out at the receiving end and makes a noise and shock which the trackmen cannot eliminate. The Belgian Government have just designed a new 117 lb. rail, and have made it even broader than my 100 lb. section; they added 1/4 in. to the width. I was disappointed in not finding as smooth riding on these heavy rails as ought to have been secured by the 105 lb. rail. The track was rough in a short time, and they acknowledge that it does not ride as smoothly as they would like to have it; and they do not understand the reason. I think that with heavier rails and less ties we can secure a smooth track with some elasticity which is better than one that is extremely rigid. On many roads it takes only a short time to wear out the 80 lb.

rails, while the 100 lb. rails will carry over 250,000,000 tons, and still be smooth before it is removed. This is due to the difference in the breadth of the rail head.

Mr. J. R. Budd: I would ask Dr. Dudley if he has made any investigation along the lines of rail corrugation?

Dr. Dudley: My broad top rails have little corrugation. One of the first things I noticed in connection with the narrow top rail was that they got rough on the curves. That is one reason why I made the head broader, and corrugation seldom occurs now on any of the broad top rails.

Mr. Budd: What is the cause?

Dr. Dudley: The narrow top rail gets the effect of the ragging of the rolls and develops the corrugation in subsequent service.

Mr. Budd: I have noticed it more on the new sections than on the old 60 lb. rails.

Dr. Dudley: Our 100 lb. rails have entirely too much work in the straightening press; they should receive more hot bed work.

Mr. Budd: The gagging introduces internal strains?

Dr. Dudley: Yes, a great many strains are introduced and after they start, they continue to develop under the wheel loads. On our broad rail head it is different; it does not wear as quickly as the rail with a narrow head.

THE DEVELOPMENT OF THE ELECTRTC RAILWAY

James N. Hatch, M.W.S.E.

Read February 11, 1904.

There is probably no branch of modern industry that has exercised a greater influence upon the social organization of this country during the past twenty years, than the Electric Railway industry. This influence began and grew to very important proportions even while electricity was used as a motive power only on the surface cars of our city streets. Even with this limited field of operation, the rapid transit afforded the suburban districts of the cities, made the modern American city a possibility; brought the outlying districts within a few minutes' ride of the heart of the city, and prevented that great congestion which is found in foreign cities. And later, with the advent of the interurban road, this readjustment of the centers of population has become much more pronounced, until the entire population of the United States is feeling the effect of the changed condition. It is not only the city person who has thus gained a great advantage in being able to appropriate the benefits of country life; but the country person is also greatly benefitted by having extended to him the valuable influence and advantages of the city.

The electric railway is thus exerting a great influence in equalizing social conditions and in breaking down the barriers that have always been felt to exist between the urban and the rural civilization of our land.

It is not possible to define exactly when electric traction cars were first invented or to laud one inventor as the originator of the electric car. In fact, the modern electric railway has been evolved from a laboratory toy, and is as we see it today the product of the minds of many men. Each successive inventor has added a little here or a little there, until the result is the successful enterprise which is now coming into so much prominence.

The idea of operating cars by electricity was put into practice, experimentally, more than seventy years ago, but at that time neither dynamos nor motors had been invented and the use of the primary electric battery as the motive power for vehicles was not at all an encouraging problem. Another circumstance that effectually retarded the progress of the electric railway was the success attained about this time by the steam roads, which seemed to solve effectually most of the important problems of transportation. A few experiments were carried on from time to time both in America and in Europe, with battery driven cars, but very little encouragement was found in these attempts. And it was not until after the year 1867, the year in which the dynamo was perfected, that any real progress was made toward a large electric car suitable for the practical carrying of passengers.

Following promptly upon the commercial exploitation of the early magneto—electric and dynamo—electric generators, came a sharp renewal of the effort to perfect the electric railway. But even then it required twenty years of experimental work before any system was so far perfected as to show evidence of real commercial success. It can therefore be said that the modern electric railway is the product of the last twenty years.

Electric Locomotive and Cars first operated on May 31, 1879, at the Berlin Trades Exposition.

However, in the few years that have intervened since a successful system has been perfected, the development of the electric railway has been very rapid and the outlook for the future is stupendous. The electric roads now in operation in the United States would, if collected together, furnish enough trackage to build a ten track line from New York to San Francisco, and the cars in use would, if placed end to end, make a continuous wall reaching from Chicago to Pittsburg. There are more miles of electric road in the United States than there in all the rest of the world put together, and the electric roads in the United States have more mileage than the combined electric and steam roads of any one European country. The present growth represents an equivalent of a new line from Chicago to San Francisco every year.

This growth and advancement from year to year has been little less than marvelous. The average rate of construction for the past six years has been 2,500 miles per year, which represents a growth per annum of more than half of the annual growth of the steam roads for the same period. And this represents practically all new work, for the changing over period had nearly ceased before the year 1900.

With these facts in mind it is not difficult ot believe that the time is at hand when the electric railway must be seriously reckoned with in the financial economics of this country. At the present rate of increase there will soon be a perfect network of interurban lines

throughout the entire densely populated portion of the United States. Probably during the present summer, electric cars will run through from Chicago to Louisville and Cincinnati, and it will be but a short time until it will be possibe to go from Chicago through to Detroit and Cleveland on electric cars.

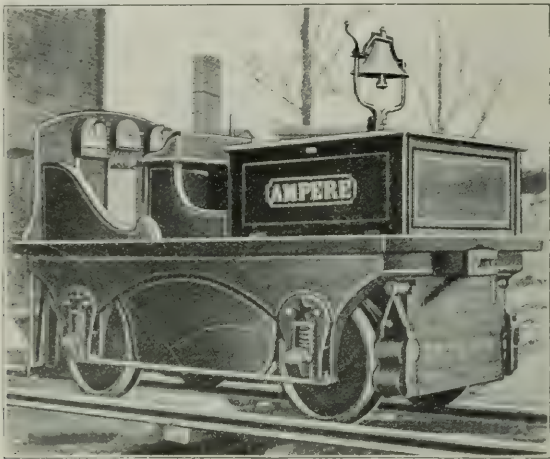
According to the United States census report of 1890, there was in 1886 two electric railways in successful operation, with a combined mileage of eight miles; in 1887 there were four roads with a combined mileage of twenty-nine miles; while in 1888 the business had increased until there were then in operation twenty-nine roads with a combined mileage of nearly three hundred miles.

For a number of years prior to 1886 there had been numerous attempts made to put in operation a successful electric car, and it was confidently believed by the various inventors that electricity was adapted to the propulsion of street railways; yet none of these attempts were so far successful as to supplant the well-established methods of operation with horses or steam dummys. While every attempt which had been made was of inestimable value in forming a stepping stone to better things, some weak spot always developed, that rendered the enterprise a financial failure. But these obstacles, while very disheartening at the time, did not seem to discourage the designers of these early days, but only served to awaken them to the necessity of renewed efforts to perfect the system which they believed destined to be rewarded with success.

As early as 1880 the electric motor had been so far perfected and simplified that the outlook for a practical electric car was encouraging, and a number of designers were in the field working on schemes to make electric traction a success. In 1881 and 1882, Leo Daft began experiments with a commercial size electric car, firm in the belief that it was possible to replace the horse as a motive power for street railway by electric traction. Mr. Daft formed the Daft Electric Co., and made a large number of public tests for the purpose of demonstrating the practicability of the Daft systems of electric traction. This company built an eleteric locomotive which they called the "Ampere," for use on the Mt. McGregor steam railroad at Saratoga, and during the summer of 1883 equipped about 1.25 miles of that road with 35 lb. third rail, mounted on resinized wood blocks in the center of the track, with soft rubber insulation under the foot of the rail and bolt heads. Experiments were continued for two or three weeks with more or less success. One feat of the Ampere is described as hauling an ordinary day coach containing 68 passengers over a curve of about 100 ft. radius up a grade of 93 feet per mile.

Following the Saratoga experiment, the Daft Electric Co. in 1884 built several show lines at Coney Island and elsewhere, to advertise to the people at large the feasability of the system. As an outcome of the Coney Island demonstration, the Daft Co. was awarded a contract for about two miles of actual street railway line in Baltimore.

This was a very trying piece of line to begin with, as there were grades of 350 feet to the mile, and curves of from 40 feet to 70 feet radius, with a gauge of 5 ft. 4.5 inches. The line was owned by the Baltimore Union Passenger Railway Co., and the contract with the Daft Co. was entered into in 1885 and work upon the equipment



Daft's Motor "Ampere," 1883.

was started forthwith. Many troubles developed in the installation and subsequent operation of the line, but it was operated with enough success to attract the attention of capitalists and to awaken ambitious engineers to the belief that there was really a power almost within their reach which was destined to revolutionize the street railway business.

Daft's Baltimore Road.

With this line an electric locomotive hauled the regular street cars. These locomotives or dummys were equipped with motors placed on the floor of the car and the axles of the car were driven by large gears. The track was equipped with a third rail to supply current,

placed midway between the track rails, which were used for the return circuit. An overhead trolley was used where long crossings were encountered, and it was in this way that the first trolley system was put into operation.

Daft says of his Baltimore road which was put in operation in 1885, that "therewith the first commercial electric railway in America had hung up its shingle."

This suburban road continued in successful operation until 1889 or until it became part of a network of electric railways which were equipped with more modern apparatus. Daft introduced the double trolley system of electric traction with a trolley wire return. This system is still in operation in Cincinnati.

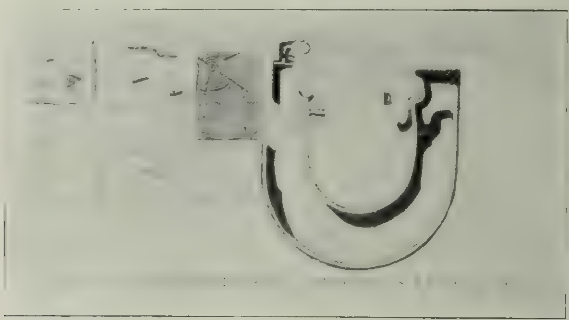
"Benjamin Franklin" of 1887-8 on New York Elevated Railway.

In 1888 Daft placed on trial a large electric locomotive, on the Ninth Avenue Elevated Railway in New York. This locomotive was called the "Ben Franklin" and was placed in service with the hope of showing the advantage of this motor over the steam locomotive then in use. These trials were conducted under a variety of conditions, in an endeavor to convince the most skeptical of the advantages of electric motive power for elevated roads. This motor was able to draw six of the ordinary elevated cars at a speed of forty miles per hour. These experiments were thoroughly successful, but the necessity of changing from steam to electricity did not seem to be apparent at that time, and in fact was not fully realized for a long time afterward.

During the time that Daft was carrying on his early experiments in the east a number of inventors in the west were making experimental efforts to demonstrate other systems of electric traction. One of these early railways which gained considerable prominence, and which was among the first electric railways successfully operated, was that at the Chicago Exposition in 1893. An electric locomotive known as the "Judge" operated for some time during the exposition on an intramural railway, and hauled 20,000 passengers. The Judge was made in accordance with the design of Edison and

Field, who had combined their efforts in electric railway design. The Judge weighed about 3 tons and drew a trail car for passengers.

In the fall of the same year Messrs. Bentley and Knight, who had witnessed the performance of the "Judge" at Chicago, formed the Bentley-Knight Railway Co., and constructed a short experimental electric railway in the yards of the Brush Electric Co. at Cleveland. The results of the experimental line were so encouraging that during the next year this company constructed a line over a mile long in Cleveland, and operated cars with more or less success and constancy for more than a year. This company used the conduit system, in which the conductor was carried in a wooden box placed between the track rails.



At the Chicago Exposition there was also another experimental electric railway built by Chas. Van Depoele. In this line the car was suspended from the rails and ran around the exposition building. In 1885 Mr. Van Depoele put in operation at the Toronto Exposition Toronto, Canada, an electric trolley railway, which it has been claimed was the first commercial trolley car line ever put in operation. This was not strictly a street railway line, but ran from the terminus of the city street railway to the Exposition grounds, something over half a mile, and was operated only during the Exposition. A motor car and three trailers constituted the equipment. On this line a speed of thirty miles per hour was attained, and an average of 10,000 passengers per day were carried. The track rails were used for the return circuit, and on top of the car was placed one of the first illustrations of the under running trolley now so universally employed.

Mr. Van Depoele's next venture was the construction of a regular street railway in South Bend, Indiana. On this line were operated as many at five separate cars, something never before attempted or even supposed possible. This road derived its current from a generating plant driven by water power. There were four ordinary closed cars equipped with one 5 H. P. motor each and one large car equipped with a 10 H. P. motor. On the cars the motors were placed under the car body between the wheels, and the axles were connected by means of sprocket wheels and link belts. This arrangement of

putting the motor below the floor of the cars, was found to be advantageous, as the earlier arrangement of placing the motor on the floor of the cars took up much valuable space which could be used for passengers. On this road an innovation was introduced in the use of the over-running trolley instead of the under-running style, as was used at Toronto. The cars on this line were not reversible, but always run the same end forward. The first use of the carbon brush motor is also attributed to Mr. Van Depoele and was put into operation on the line.

Prior to the introduction of the carbon brush on railway motors, the brushes used were similar to the then prevalent type of dynamo brushes made of thin strips of copper. These brushes were a never ending source of trouble in railway work, due not only to their inherent unreliability under the rough use on a railway motor, but due also to the trouble from dirt and moisture which was encountered along the unimproved streets. These early motors were of the open type and offered little protection from dust and weather.

Some of the early types of motors were fitted with two commutators and two sets of brushes, one on either end of the armature, and is was no uncommon thing for the motorman to stop two or three times per trip and put in new brushes.

An Early Electric Car with Motor on Front Platform.

The rheostat or resistance for regulating the speed was also a complicated and annoying piece of apparatus. It was at first placed beneath the car and manipulated by a coffee mill style of controller, which the motorman ground around two or three times to throw on the power. Afterward this rheostat was placed upon the platform, but was always a menace to life and limb.

These things seem amusing now as we examine them in a reminiscent way, but they were most exasperating at the time, for an exhibition of trouble on a street railway car, partook of so much publicity from the very nature of things, that every little trouble seemed to be magnified, and it was hard to convince the public that

such troubles were only transitory, and that their discovery meant their elimination. It required just such enthusiastic experiments as the South Bend road to show up the weak spots and pave the way for better things.

Following the construction of the South Bend road, Mr. Van Depoele built a large number of lines, under his system, during the next few years, some of which continued in operation and some of which fell by the wayside. One in particular, which was constructed in Windsor, Canada, in 1886, was remarkable to the writer as constituting the first electric railway which he had ever seen. He visited Windsor and examined the railway with a great deal of interest. At the time of this visit the road was in a state of inocuous destuetude and apparently had been in that state for some time. The one car, the total equipment of the road, stood at the end of the line, where it had apparently stood motionless for many moons. The trolley was a miniature car which was drawn along the trolley wire by a flexible conductor.

The Van Depoele Co. was absorbed by the Thompson-Houston Co., in 1888 and Mr. Van Depoele became an engineer for that company. The following year the Thompson-Houston Co. took over the Brush Co., which also brought the Bentley-Knight Co., into the consolidation.

At about this same time Mr. John C. Henry, of Kansas City, was working on an electric railway system of his own invention, which attracted considerable attention. He put in operation several experimental lines, using the Van Depoele motor and the trolley collector with overhead wires. In the fall of 1885 he conducted a series of experiments with heavy electric equipment, on a branch of the Fort Scott Steam Railway, where freight cars were hauled by electric motors. He also attempted high speeds and operated over heavy grades under all sorts of varying conditions to demonstrate the practicability of equipment. These experiments were carried on during severe winter weather, to demonstrate the effect of deep snows. The following year he equipped the Kansas City Fifth Street Railway with his system. In 1887 Mr. Henry moved to San Diego, California, where he built a number of lines, one of which had grades of 9%. The system of underground feeders was first introduced on one of these roads.

Coincident with Mr. Henry's work in Kansas City, some interesting work was being carried on in Denver by Professor Sidney H. Short, of the University of Denver, upon an experimental electric railway 300 or 400 feet long upon the college campus. Professor Short believed in the series system of distribution and used this system on his lines. The cars used on the campus line had a rigid four wheel truck, and the motors were geared with one pinion and gear to the axle. The car body was eight feet long. The success of this line was so great that a party of capitalists induced Mr. Short to give up his professorship and develop a commercial

electric street railway. The conduit system was adopted and five miles of track were laid on 15th St., Denver, and operated with considerable success for some time. The difficulty of insulation in the conduit in wet and snowy weather and the imperfection of the early types of motors and generators led to electricity being finally abandoned for the cable, which, however, has since been changed back to electricity.

Mr. Short afterward went to Columbus, Ohio, and later to Cleveland, where in 1889 he organized the Short Electric Railway Co. This was merged into the Walker Electric Co. shortly afterward, and the Walker Company was finally taken over by the Westinghouse Electric and Manufacturing Co.

It is thus seen that the early eighties were active years in competitive demonstrations of electric railways, but all of these enterprises were more or less experimental, and all of the equipment used prior to 1887, was destined to be superseded by more economical and efficient apparatus.

With the year 1887 began the actual construction of actual roads, for with that year the vast numbers of previous experiments began to bear fruit in the way of practical results.

On December 31st of that year there were twelve successful electric railways being operated in the United States and Canada with an aggregate mileage of less than fifty miles of track. The electrical equipment of these twelve roads consisted of fifty or sixty motor cars. Of these roads, six were on the Van Depoele system, three on the Daft system, and one each on the Fisher, Short and Henry systems.

The Edison Electric Passenger Locomotive of 1882

This was the situation when Mr. Frank Sprague entered the electric street railway field. There was no standard of construction either in size of cars, style of equipment, gage of track, kind of rail or method of power transmission. Mr. Sprague had been

working for a number of years upon the perfection of his motor and had established himself in the field of stationary electric motors before attempting to use his motors for railway service. And his first active work in this line was begun in 1887. Prior to this he had done considerable experimental work with his motor in New York upon a private track and upon the 34th Street branch of the elevated railway.

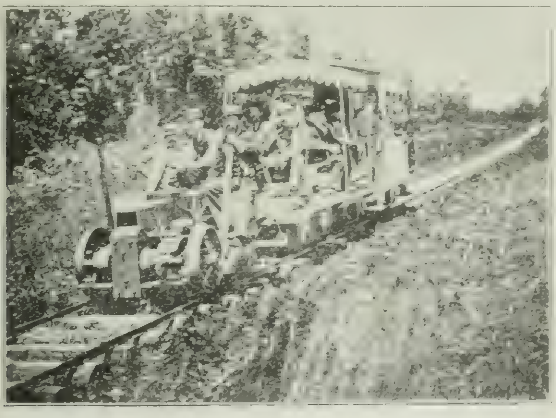
In the spring of 1887 the Sprague Electric Railway and Motor Co. received contracts for roads in St. Joseph, Mo., and Richmond, Va. The Richmond road is generally referred to as the first successful electric railway ever constructed and while this does not imply that the roads of Van Depoele, Daft and others would not have been successful when the obstacles were overcome, and in fact were improved afterward until they were successful, it still remains a fact that the Richmond road was the first to work out of the preliminary difficulties and attract attention as a thoroughly successful commercial enterprises, worthy of copying.

After twenty years of development we would now look upon the construction and equipment of the Richmond road as a boy's size affair, but at that time it was the biggest thing of the kind ever attempted. The road was a new one, as distinguished from the changing over of horse car lines, and included a complete generating station, erection of overhead lines, and equipment of forty cars with two 7½ h. p. motors each, on plans largely new and untried. The contract required that it must be possible to operate thirty of these cars at one time. The conditions in Richmond made the requirements for grades and alignment very severe, and the road as built had 29 curves, some of them of less than 30 feet radius and grades reaching 10%. The contract required the completion of the entire track ready for operation in 90 days. The track was laid with 27 lb. rails. The overhead construction consisted of a small trolley wire reinforced with a continuous main conductor placed over the center of the track and supplied with current by feeder circuits from the main power station. The track constituted the return circuit, the rails being bonded together and connected with a continuous conductor, which was also connected with the ground plates and with the water and gas mains of the city. The power house was equipped with small belted units and generated constant potential current at about 450 volts. The cars were 16 feet in length, and as said, were equipped with two 7½ h. p. motors. These motors although built according to the best known design at that time, constructed in one of the best equipped electric manufacturing shops of the country, were so poorly adapted to the service that was required of them that every one of them required the rewinding of its field coils and armature and the changing of its commutators. The principal characteristics of Sprague's motor-equipment as used on the Richmond road, which contributed largely to its success and was an improvement over earlier systems were, an independent truck

with motors exteriorly centered upon the driven axle so as to maintain parallelism between the driving shaft and the driven axles flexible supports for part of the weights of the motors on the trucks to allow perfect freedom in following the motion of the axles, suspension being below the car springs. The method of flexible suspension avoided all shock and jar. He also used fixed brushes, allowing forward and backward running. This equipment marked the abolishing of ropes, belts, sprocket wheels and chains for the reduction between armature and axle.

In spite of many difficulties and a host of obstacles which had to be overcome, the Richmond road was a success and continued in operation until it was later absorbed by a more modern system. This road attracted wide attention in street railway and financial circles.

The Sprague Electric Railway and Motor Co. depended largely on the Edison General Electric Co. for the manufacture of motors, and in this way the Edison Co. became interested in the electric railway field. The Edison Co. advanced money to Sprague to carry on his business, a consequence of which was that the Sprague Electric Railway and Motor Co. was soon absorbed by the Edison Co., all of which were later merged into the General Electric Co.



The first Edison Electric Locomotive and train, 1880.

After the year 1888, the electric railway business of the United States was established on a firm basis. The large electric manufacturing companies which had already developed an extensive business in the electric lighting field, became interested in the manufacture of electric railway equipment. The Thompson-Houston Co. was one of the pioneers in railway motor construction. The first step in this direction was the purchase by it of the patents of Bentley and Knight and those of Van Depoele. Shortly afterward the Thompson-Houston Co. took over the Brush Co. and began on a large scale

the construction of railway motors. The services of Mr. Van Depoele were also secured in the designing department of this company. The first motors turned out by the Thompson-Houston Co. were what were known as the F-30 motor. This was a 15 h. p. motor, and two were used to the car. Four thousand six hundred of these were sold by this company during the years 1888-91. These are said to be the first motors on which the carbon brush was used. Without the carbon brush the railway motor could never have attained the success it has.

In 1890 the Edison General Co. took over the Sprague Co. and actively entered into the manufacture of railway equipment. Shortly after this, several of the men who had been active in the Sprague Co., and who owing to the consolidation of the Sprague and Edison companies, were left on the outside, induced the Westinghouse Co. to take up the manufacture of railway motors.

Thus with the year 1891 there were three large companies actively competing for this class of business. In 1892 the Edison General and the Thompson-Houston companies were merged into the General Electric Co. Since that time this company and the Westinghouse Co. have been the two principal factors in electric railway manufacture. The Westinghouse Co. in 1898 took over the Walker Co., of Cleveland, who had eight or nine years previously secured the services of Professor Short as Chief Engineer.

During the six years from 1888, the time when the success of the street railway was assured, to 1894, when the street railway began to expand into the interurban railway, the growth of the electric street railway was very rapid. During these six years the electric railways of the United States increased from less than 300 miles in 1888 to over 10,000 miles in 1894.

It must be remarked, however, that this does not represent new enterprises altogether, for it was during this time that a great majority of the horse car lines and steam dummy lines were changed over to electricty. It is shown that in 1888 there were 289 miles of electric railways and 6,800 miles of street railways propelled by other means; in 1892 the electric railways exceeded the combined mileage of all other kinds of street railways, there being 5,934 miles of electric against 5,695 miles of all other kinds, while in 1894 the electric railway had to its credit 13,598 miles of line, against 3,225 miles of all other kinds. This information should be considered in connection with the fact that cable railways continued to increase up until 1894.

The most interesting problems in electric railway construction after 1894 were in the development of the interurban lines and the electrification of the elevated roads in New York and Chicago.

The elevated railway had proved its usefulness in several of the larger cities prior to 1894 but cars on these had all been propelled by steam power. These steam roads were successfully operated in the east for a number of years and seemed to give good satisfaction,

RAILWAY STATISTICS.

United States.			Foreign Countries.		
Years	Steam Rys. mis.	Electric Rys. mis.	Country	Steam Rys. mis. '08	Elec. Rys. mis. '00
1880	93,262	-------	Germany	30,777	3,000
1885	128,320	-------	Austria	21,805	[illegible]
1886	136,338	8	Gt. Brit.	21,529	2,400
1887	149,214	29	France	25,898	1,200
1888	156,114	289	Russia	26,414	
1889	161,276	805	Italy	9,759	105
1890	166,654	1,262	Belgium	3,781	35
1895	181,065	12,133	Neth'lds	1,965	983
1900	194,262	19,314	Switz'ld	2,302	109
1905	217,341	33,100	Spain	8,103	349
1906	222,200	35,000	Sweden	6,359	

and were profitable. But in Chicago the conditions proved different, either because their installation in Chicago came at a time when the people had become educated to something better, or because the people of Chicago would not be contented with a class of transportation which was considered adequate by the people of Boston and New York. At any rate the elevated roads which were started in Chicago with steam locomotives did not prosper, and it was not until electricity had been substituted for steam that these roads proved successful either from a financial or popular standpoint.

The intramural railway at the Chicago World's Fair was the first electric elevated railway put into operation in the United States, and its very successful operation proved the practicability and reliability of electricity as a motive power for elevated railways, demonstrating the correctness of the contention made by Daft, Field, Sprague and others who had carried on their experiments on the New York elevated roads, that electricity was superior to steam for that purpose. The third rail method of current distribution was also thoroughly demonstrated on the intramural road, and there was no further doubt of the thorough reliability of electric elevated railways for heavy traffic and frequent stops.

The Metropolitan Elevated Railway, in Chicago, was already projected at the time of the World's Fair and was designed for the use of steam locomotives. The Lake Street Elevated and the South Side Elevated were already in operation with steam locomotives. After the success of the intramural railway the Metropolitan Railway cancelled the orders for steam locomotives and decided to adopt electric motors. The plan adopted, was for a large electric motor car which acted in the place of the steam locomotive and hauled the train, all of which was composed of trailers. This was the first regular city electric elevated railway ever put into operation.

Largely as the result of the success of the intramural railway the Northwestern Elevated was projected in 1893, and the franchise was obtained with the express understanding that the road would

be operated electrically. This was the first electric elevated railway ever designed, as such, in the United States. This was also the first four track elevated road in Chicago, if not in the United States.

Not long after the World's Fair the South Side Elevated Railway decided to change its motive power from steam to electricity At first thought this no doubt seemed a comparatively simple problem but a little investigation unearthed some very obstinate difficulties which seemed almost unsurmountable, if a single electric locomotive were to be used to haul a train of three or four cars. The need of long trains on this line was already obvious, but the structure was not heavy enough to safely carry such heavy motor cars as would be required to draw these trains. Mr. Frank Sprague, of New York, was invited by the engineers of the South Side Co. to invesigate the problem and submit a plan for the electrification. He very strongly recommended a system which he had invented a short time before, of multiple unit control, by which every car in the train could be a motor car if desirable and all could be operated by a master controller located at the head of the train. This system had not been put into practical operation prior to its use on the South Side road, and there was considerable speculation as to its practicability. But after the first few trials which developed some rather serious miscalculations, the system worked splendidly. The system of multiple unit control has been very generally adopted in all electric train operation since its installation on the South Side Elevated. A short time after the Chicago Elevated roads had changed to electricity, the New York Elevated followed.

Another interesting electrification problem which was carried out at the same time that the first elevated roads were changing to electricity, was the adoption of electric locomotives for hauling the steam trains through the Belt Line tunnel of the Baltimore & Ohio Railroad in Baltimore. The first of these locomotives was put in service in 1895. The use of steam locomotives in long tunnels had always been known to be a dangerous practice, owing to the deadly gases from the burning coal. There had already been a number of bad accidents in tunnels in which a number of lives were lost and the need for a safe substitute for the steam locomotive had been very urgent for a long time. So the use of an electric locomotive for this purpose was felt to be very desirable, and this effort to use an electric locomotive in the Baltimore tunnel was watched with great interest. The success of this venture into an unknown field, was assured almost from the start, and the electrification of other tunnels have followed. It goes without saying that all the newer tunnels now being constructed beneath the rivers in New York, Detroit and elsewhere for steam railways, will be operated electrically, and further than this, in many of the mountain tunnels of the west there is now under consideration the electrification of certain systems of road involving these tunnels. Another circumstance that makes this class of electrification desirable is that electric locomo-

tives are much more efficient than steam locomotives on heavy grade, and heavy grades and mountain tunnels are generally found in close proximity.

The first interurban railway to be put in operation seems to have been out of Cleveland, although it is hard to distinguish between the urban and the interurban in many cases where the street car lines were extended further and further out of the cities along the country roads until they finally connected one city with other towns and cities and thus become interurban.

One of the earliest premeditated lines to be constructed was the Akron, Bedford and Cleveland. This road is 35 miles long and was first planned in 1892 and 1893, and was put in operation in 1894. At that time the direct current transmission at a low voltage was the best known method of distributing current to the cars, and a line 35 miles long was a gigantic enterprise. In 1894 not only was high tension transmission unheard of for electric railways, but the art of high tension transmission for any purpose was only in its infancy. It will be remembered that it was not until the following year that the Niagara Falls transmission line was put into operation, and this has been considered the pioneer high tension transmission line in this country, although there were some lines on the Pacific Coast constructed about this time.

The real growth of the long modern interurban railway began with the introduction of the rotary converter and high tension alternating current transmission into railway work. The first practical proposal for a line designed to use high tension alternating current and rotary converter sub-stations seems to have been in 1896, by B. J. Arnold, in plans for a road to run between Chicago and the Wisconsin Lake region. There was a rotary converter used prior to this in connection with a railway in Concord, New Hampshire, where the power was derived from a water power plant, but this was at that time looked upon rather as a makeshift. Mr. Arnold's road to the lake region was never built, but the plans were utilized two years later upon another line which was operated very successfully from the start.

The central power station had been developed in the meantime with the introduction of large direct connected units, replacing the small belted units previously employed. The efficacy of this method of power generation had been proved at the Chicago Worlds Fair in connection with the intramural railway. The large central power station seems now an indespensible adjunct to all modern interurban lines and is being substituted for the small isolated plant for every kind of electric railway. The intramural power plant was for D. C. current entirely, as in fact were all railway power plants prior to 1896, but the principles demonstrated applied equally well to either D. C. or A. C. distribution.

As soon as the fact was fully demonstrated, that long electric lines were entirely feasible with A. C. distribution of power, the art

of electric railroading had established itself on a permanent basis. And as fast service was established, the steam roads' standard of construction was adopted. On the best lines that have been constructed in the last five or six years, the grades and curves have been made very gradual and the rolling stock has been made capable of high speeds. The fact has now been demonstrated beyond dispute that as high speed can be attained by electric trains as by steam trains, and there seems to be no question but that the ease and safety will be favorable to the electric line.

The running of the long electric lines immediately parallel and adjacent to the competing steam lines has appeared to the layman an inexplicable riddle, but the reasons for this apparent phenomenon are sound business reasons.

The writer predicts that in the future the electric roads will push more and more out into the undeveloped country, especially where water power is available, and as the freight and express business become more important factors.

The electrification of steam lines is becoming an accomplished fact, as illustrated by the New York Central R. R. in New York, and the other changes of less magnitude in the East. How rapidly this change from steam to electric propulsion of trains will be carried out on the trunk lines is hard to predict, but that the change will be made seems to the writer a foregone conclusion. The high speed electric railway is with us to stay. How great the change it will bring about in the civilization of this country is not possible to predict.

DISCUSSION.

Mr. W. D. Roper, (Chairman): The development of the electric railway has been one of the marvels of the age; the entire development having taken place within the memory of nearly all of us; it is something we have all been able to watch and note the progress. In looking forward to new developments in any line, it is expedient to occasionally pause in our forward progress and note the lines in which the development has taken place,—as a surveyor would put it, in order to be sure your forward progress is on proper lines, you want to make sure of your back sight.

Mr. Hatch has gone very thoroughly over the development of the electric railway system—its evolution from the early beginnings. A great many of the early attempts have been noted and watched by many of us, and some of the illustrations which appeared on the screen are similar to some of the scenes here in Chicago.

The remarkable development of the electric railway system may perhaps be compared to the growth of the lighting systems in the country. The lighting and power business has, as you all know, undergone a very remarkable and rapid growth, especially in the larger cities. In making a study of the electrical development and prospective development in one of the large cities some years ago,

I found that the power used by the electric railway systems in a number of the large cities averaged about three times the amount of power supplied by the public service corporations in the lighting and power business, and that ratio is approximately true at the present time, not only in Chicago but other large cities; that is, the total electric railway power is about three times the total of the commercial lighting and power business. This may give one some idea as to the magnitude of the railway business as compared with the lighting business, especially as we add to that, the amount of power used in connection with the very numerous interurban systems.

The traction systems in Chicago, as you all know, have been very materially influenced in the past few years by the franchise question. That situation has developed rather an unusual condition, especially as to the improvements, growth, and extension in the past few years. The traction companies all being forced by public sentiment to improve their service, yet in a position where it was difficult to secure additional funds for extension of their plants, and further, in their negotiations with the city they were given but a limited time in which they guaranteed certain improvements. As it was very difficult to install additional generating machinery in that period, as well as difficult to secure the required capital, the traction managers found that they could secure power for their purpose in the required time from the Commonwealth Edison Co. In fact they were able to secure power in this manner by means of underground cables from the generating stations of the lighting company as fast as they could secure rotary converters and cars. The result of this situation is that the local lighting company, for several years past, has secured all the increase in the load that has taken place in all of the surface lines and several of the elevated lines. At the present time about half of the output of the local company is used for railway purposes.

Mr. Lincoln Nissley: When I came here this evening I did not expect to enter into the discussion of the paper, not being a member of this Society, but the excellent treatment of the subject by the author of the paper, and the attractive views shown, has brought my reminiscent mood into play.

The very early demonstrations that we have had, in this country especially, have been very clearly outlined in Mr. Hatch's paper. In looking back over the past, it seems to me there were a great many more engineering difficulties than at the present time. Financially, the early pioneers in the Electric Railway field were handicapped also, owing to the fact that very few capitalists would advance the money for a liberal exploiting of the systems, and they were simply groping along the best way they could. For instance, the Sprague motors were made, not in one shop but certain parts were made in one place, other parts in another, and they were finally assembled and shipped to Richmond and other places, and placed under old

horse cars, totally unfit for the purpose when compared with rolling stock of today.

I remember visiting the Richmond road, and in riding out over the road, I noticed that the joints on the track were bent and hammered down probably half an inch, and an inch in some cases, on account of poor track construction. Many of you will doubtless remember that it was thought at that time that bonding was not necessary, and the first bonds used were galvanized iron bonds, fastened to the rails with drift pins.

The early roads of Daft were equipped with cars of the locomotive type, hauling trailers. I can remember distinctly of seeing one of those types fixed up as one of the big show pieces, when it was considered as the most modern car.

An early type of car consisted of the Westinghouse gearless motor (thirty-two of which were in operation at that time), and also the Short gearless motor, but that type of motor gradually dropped out of use. But now, in our heavy locomotive work, we are getting back to the gearless motor once more.

I do not wish to disagree with anything Mr. Hatch has said in his paper, but I think credit has been given to some people where it does not belong. For instance, Mr. J. C. Henry was a very early pioneer in electric railway work. In 1888 he invented a regenerating controller. His idea was that when the car was going down the grades, the motors would generate power proportioned to its speed and deliver it back to the line, but he never succeeded in making a success of the regenerating controller.

The early motors of Sprague, Daft, Henry, Van Depoele, Bentley, Knight and others were of the double reduction type. Of course we who have seen the operation of those open motors, know that they were not waterproof, and they soon deteriorated, and on account of the great cost in keeping them in repairs, etc., they were soon replaced by the enclosed type, or waterproof motor. The first waterproof motor made in this country was manufactured by the Thomson-Houston Co. before its consolidation with the Edison Co. I have seen, personally, some of these motors operating in the street where there were two or three feet of water, and they operated without being burned out, which was thought at that time a great advance in the art.

The evolution, advancement and remarkable progress made in the electric railway field is beyond any engineering progress in this country. Today our motors are not only much higher in efficiency, but will operate from two to three months without any care whatever, and that is quite an item when it comes to winding up the year's affairs and getting up the profit and loss account.

Again, in speaking of the electrical railway development, Mr. Hatch is correct in saying that the Akron, Bedford and Cleveland line was the first interurban railway in this country. I might say that a double current generator was manufactured by the Westing-

house Co. for this road for the purpose of transmitting direct current from one side of the machine out a certain distance, on the line, and then from the other side of the commutating part of the armature taking alternating current and transmitting at a great distance or beyond the economic distance alowable for 600 volts direct current.

One of the largest single phase installations, is the Indianapolis and Cincinnati railway. The company has 147 miles of road, and they operate at very high speed, 50 ton cars, and very successfully, too. Personally, I consider that that is the first successful single phase electric railway in this country for long distance interurban work. Of course the New York, New Haven and Hartford single phase electrification is on a much larger scale. The great controversy that was at one time going on between the advocates of the overhead trolley and the third rail system has disappeared entirely from the arena. Daft's old Mt. McGregor road has been again brought to the front in its type of construction; the Hudson and Albany line being a similar installation, so far as the third rail goes.

The patent controversy was a great hindrance in the early introduction of the electric railway, and the large electric companies spent several million dollars annually to protect patents. This difficulty, fortunately, has all disappeared from the field.

As to the results of our interurban railroads, I would like to say this,—that so far as opening up communication between the larger and smaller centers of population is concerned, they have been a great success. From a financial standpoint, however, some of them have been failures, for out of the fifty-seven railways in Ohio only eight paid dividends last year. The question must arise,—are we going to develop further the interurban railroad in the United States? We certainly will continue, but there must be some returns for the capital invested; the railroads must earn some money on their initial cost. If you are at all familiar with statistics of the roads in the middle west, you may remember that the electric railway costs, per mile of road bed, from $20,000 to $30,000; so the earning capacity must be somewhere from $3,000 to $4,500 per mile of road bed to pay interest on the investment. By observing the statistics of the census reports, one will find the cost running up from $50,000 to $65,000 per mile of road bed, and that the earning power is only about $2,000 to $5,000 per mile, yet companies are continuing to go on and do what no other railroad has ever done in a certain respect. They have done what, in my judgment, the steam railroad never did in its early days,—carry a passenger for so small a fare,—deliver him speedily, safely and every hour of the day at his destination. As has been remarked here this evening, the electric railway is one of the marvels of the age; let me add that it is here to stay no doubt, and will continue to develop as a potent factor in the vast transportation systems which are yet to be on this continent.

Mr. W. E. Symons, M.W.S.E.: I have been much interested in this

paper although not an authority on the evolution or development of electric railways, or electricity as a means of propulsion.

Mr. Hatch's paper has made both of these matters very clear, particularly the conception and early development of electric propulsion, and this information so ably prepared and presented will become more valuable to this Society and to the engineering world, as time goes on, and the records from which such information must be secured become more obscure. This very able review, together with Mr. Nissley's remarks, has prompted me to ask some questions of the author, or possibly Mr. Nissley may feel disposed to answer some of them.

All of us who have observed the development of anything of a scientific or mechanical nature can recall, that the early efforts have usually met with very slight encouragement, and not infrequently open ridicule, or hostility; all of which added to the disadvantages to be overcome. This has been especially marked with reference to all great factors in our modern civilization. Taking, for instance, the first efforts to develop the steam boat: John Fitch, who was one of the first and most worthy of recognition, was looked upon by some as of unsound mind. After he had built his second boat, and with much effort had induced some friends, whom he hoped to interest both in a scientific and financial way, to inspect the craft, he said to them "Gentlemen, it may be after my time, but this will eventually be the means of carrying both freight and passengers not only in our coastwise trade and rivers, but across the ocean." As the friends turned to walk away, one said to the other "What a pity the poor fellow is crazy." Similar treatment was accorded the early inventors of steam locomotives; it was the same with the telephone and electric propulsion.

It is not a long time since a very bitter controversy was going on between the two principal leaders in the electric development of this country, as to the relative advantages of their respective systems of electric propulsion.

The patents under which these two systems were manufactured having been pooled I think it would be interesting to know if any conclusion has been reached between, or by, these former contending companies, or the users of either systems as to which is the most desirable, practicable and economical, and what, if any, objectionable features formerly so strongly emphasized by each company with reference to the other's system has in any measures been eliminated, or improved upon.

Some two years ago the country was startled by the announcement in the public press of a terrible railway accident, wherein passengers were killed; some having suffered death by fire. The newspapers commented much on this, and pointed out that if electricity were used as a means of propulsion, danger to passengers and property from fire was impossible. A few days following this, however, a very bad accident occurred on one of the prominent railways

running out of New York City, which had been recently electrified; the results in the latter case were almost as disastrous, both to property, life and limb as in the former. In fact, if the newspaper accounts were correct, some of the passengers suffered death from burning, which would indicate that even on electric trains passengers are not entirely free from the danger of fire.

In the matter of relative cost of steam and electric railways, while this does not come within the scope of the speaker's paper, it would be very interesting to know his views as to the relative cost of a horse power delivered at the draw-bar of an electric locomotive as compared to that of a steam locomotive.

In the matter of electrification of steam railway terminals referred to by Mr. Nissley, will say, there are a number of intricate problems in connection with work of this kind, which yet remain unsolved; this is particularly true with respect to the question of providing adequate switching facilities. Main line trains are very easily and successfully handled, but the question of switching in the yards where trains are assembled for departure, and in handling industry track work, is very complex, and if the author of the paper, or Mr. Nissley, could offer some suggestions in connection with this feature of electrification, it would be very interesting.

Also if any data has been compiled as to the schedule of electric equipment to date, showing the number of electric locomotives in service in America at the present time.

Mr. Roper: Two of the speakers this evening have referred to the patent situation. During the last ten or fifteen years this has been an important feature in electrical developments. About twelve years ago I was connected with one of the large manufacturing companies—the time when the patent situation was at its worst. At that time one of the largest manufacturing companies controlled the patents on the controller and the trolley. Another company controlled the polyphase transmission patents, as well as the fundamental patents on transformers. These were the principal patents, and each company was very industrially engaged in collecting testimony and evidence of various kinds which would render void the patents of the other company. Personally, I was engaged in making experiments on some machines which had been brought over from Paris, which had been in use some ten or fifteen years before that time, and which combined all the elements of the modern polyphase alternator. These machines were built by Mr. Gramme and were two-phase revolving field machines with removable pole pieces. We succeeded in running one as a two-phase generator and one as a self-starting two-phase motor. The indications at that time were that each company would be successful in producing information that would nullify the patents of the other. About this time it developed that if each succeeded in doing this it would immediately open up the entire field to all competitors, and so, rather than do this, they apparently agreed that it would be a better commer-

cial solution of the problem to pool the patents than to nullify all their patents and thereby open up the entire field. Shortly afterward, the experiments were discontinued, and the matter quieted down, and not many months afterwards the patent agreement appeared.

Mr. Hatch: I am not prepared at this time to answer the questions which Mr. Symons has asked.

Mr. Nissley: The reference I made to patents was simply to bring out the point that we had great success after pooling the patents, and I think the Chairman has voiced my sentiments and answered that question. While I might have been a little perverse at that time in making that statement, it has had nevertheless great influence in forwarding the electrical industry.

Mr. Geo. M. Mayer, M.W.S.E.: Referring to some details which the speaker of the evening brought up—the brush troubles more in particular. The motor was not perfected at that time, and a good deal of sparking from the metal brushes was met with, hence the commutator of the dynamos or motors had to be turned down frequently. This trouble was avoided through the introduction of the carbon brush. The electric cars were merely remodeled horse cars, and followed no particular design in conformance with the general equipment. This matter, as we know, was adjusted later on.

Mr. Roper: The tractive effort of a steam or electric locomotive is largely a matter of weight. The electric locomotive, with the same weight, can probably produce a little larger tractive effort, because it has a more uniform pull than a steam locomotive.

There have been a number of amusing instances along that line, one of which I learned recently from one of the engineers of the New York Central Railroad: One of their steam locomotives used for drawing tarins, in going through the tunnel near the Grand Central Station, stopped and was unable to start up the grade. Shortly afterward, another train came along, and the second locomotive was unable to push the first one out. This trouble was probably aggravated by the gas and fumes in the tunnel, but the fact remains that, shortly after this a third train came along with an electric locomotive, and succeeded in pushing the two trains out. This incident created considerable comment at the time, and the steam locomotive engineers could not understand how the electric locomotive was able to develop sufficient power for the purpose. Local conditions were probably a large factor in the case, and the electric locomotive was not at all bothered by the fumes and gases in the tunnel. Also, the electric motor, as we all know, has the power of developing considerable overloads for a short period without any difficulty whatever.

Mr. Symons: It is barely possible that my question with reference to the relative cost of steam and electric horse power was not made perfectly clear. What I wish to get at is the cost of producing a horsepower at the draw bar of any particular unit that might be considered. To make the matter more clear, we will consider the

steam locomotive; among the most efficient engines that were tested on the testing plant at the St. Louis Exposition one of these delivered a horsepower at the draw bar with a consumption of 2½ lbs. of coal per hour. In actual service on the road in handling trains, however, the amount of coal would be very much in excess of this, possibly more than double; this for various reasons; the conditions are less favorable on roads in every way, the engines being outdoors, there is greater loss of heat. Again, the quality of coal furnished for use in laboratory work is invariably good, while that furnished on the road is universally of a more inferior quality. Therefore, the number of pounds of coal consumed per horsepower would probably run about 5 under the most favorable conditions, and frequently to 8 or 10 lbs. where the coal was bad, and it was the relative quantity of fuel consumed necessary to produce a horsepower at the draw bar between the electric and steam locomotive, which I had in view.

The pulling capacity of any locomotive, as the Chairman has well said, is governed largely by its weight, as the weight bears a direct relation to the ratio of adhesion, which in steam locomotives for freight service is usually about 1 to 4½ or 5, while with passenger locomotives it is usually about 1 to 5.

The amount of tonnage, or weight of trains that a locomotive will start depends on a number of things: Principally, the tractive power of the engine; the condition of the rail has much to do with this, and in the matter of the speed of trains the size of the boiler and the relative ratio between cylinder volume, heating surface, evaporating surface and grate area are all controlling factors in the effiicency of the machine, and, therefore, governs its performance. The type of steam locomotive in most common use has a less starting efficiency than an electric locomotive of the same weight for the reason, that the torque, or turning moment of the electric locomotive is maximum and constant at all points, and at all times, while the steam locomotive referred to, has dead points, which effects its efficiency or power. This principle is very clearly shown in the improved steam locomotive of the 4 cylinder balanced type, which provides a more constant turning moment, or torque, which approaches very closely to the efficiency of an electric locomotive in the matter of starting from a period of rest. The question of efficiency to move trains of a given weight over certain distance, however, is governed entirely by the size of the boiler, and its ability to provide steam for this purpose. The limitations of a steam locomotive is, therefore, fixed and determined by the size of its boiler, while that of an electric locomotive is governed by the power plant where the electricity is generated for its propulsion.

Mr. Roper: Regarding the starting and accelerating of trains, some of you may recall the experiments carried on some years ago by the New York Central R. R. They had a track several miles in length built by the side of their main track; they had a dummy train,

consisting of the standard passenger train, loaded with sand bags. After they got in full working order, one of the favorite "stunts" of those in charge of the electric train was to get at one end of their experimental track and then wait until one of the fast trains came along at full speed. The electric locomotive would start as the engine of the fast train came alongside and would then accelerate so fast that the two would be running at the same speed before the last car of the steam train got by the electric train.

Mr. Nissley: Mr. Chairman, you have expressed it very well indeed when you stated that the advantage of the electric locomotive over the steam was first the large capacity of the electric locomotive for overload, and, second, its very high acceleration.

As Mr. Symons has stated, it is not always possible to get the full benefit of the steam locomotive, owing to certain conditions, such as quality of coal, draft, temperature, conditions of track, etc. The rating of a steam locomotive is based on the maximum tractive effort which it is capable of giving, while its capacity depends on the maximum speed at which this tractive effort may be developed.

The maximum rate of dong work, therefore, for which it is possible to design a steam locomotive is established by practical limitation as to steaming capacity of the boiler and width and length of fire box.

The electric locomotive on the other hand does not generate its own power, but acts nearly as a transmitting medium through which electric power delivered to the locomotive is converted into mechanical power at the driving axles. Each driving axle of an electric locomotive being equipped with a motor, the size and horsepower which is limited by the speed at which it operates, by the gage of the track, and by the diameter of the whole, it becomes only necessary to provide a sufficient number of driving axles to permit the electric locomotive to deliver the greatest tractive effort that the draw bars of a train will stand at any speed permitted by considerations of safety in operation, and reasonable cost of track maintenance.

Herein lies the chief advantage of the electric locomotive, the increase in speed of the heavy freight trains making it possible to double and in many cases triple the tonnage capacity and consequently the earning power per mile of track. For example, the most powerful steam locomotive in existence—the six-axled, twelve-wheeled, Mallet Articulated Compound, built by the American Locomotive Co., for the B. & O. R. R.—will develop its maximum effort of 71,500 lbs. working compound at a speed of less than 10 miles per hour, whereas an eight-axle electric locomotive having the same weight on drivers, and composed of two four-axle sections, coupled together, could be made to develop an equal tractive effort at a speed of 30 miles per hour.

It will be seen that such an electric locomotive could handle three

times the daily tonnage of the Mallet Compound, increasing the traffic capacity of the road in the same proportion.

The paper so ably presented here this evening by the author should be of especial value to the younger members of the profession of engineering, in spreading before them the entire results of nearly twenty years of accurate information of the more or less chaotic experiments which have led up to the comparatively staple standardization of today.

It is generally difficult to see the end from the beginning, and the application of electricity to transportation is no exception. It is therefore no small satisfaction to know that the electric railway as first installed formed the basis of the world's greatest and most pregnant industry.

THE PASSING OF THE STEAM LOCOMOTIVE

By Wilson E. Symons, M.W.S.E.

Presented Feb. 19, 1908.

INTRODUCTORY.

The title, under which this history of the development of the steam locomotive will be reviewed is somewhat ambiguous, if not misleading. An apology for its use lies in the fact, that a large percentage of the English speaking people, particularly residents of the United States who are in touch with, and are more or less familiar with the development of commerce, transportation and the growth of the country, have very little, if any, knowledge of the origin, growth and development of one of the greatest factors in American civilization, and many, some of whom are authority on the greatest problems of the day, actually believe that the term used, "Passing of the Steam Locomotive," is appropriately applicable in its literal sense.

It would, therefore, seem not inappropriate to review the history and development of the steam locomotive and let this review serve as an answer to such, as may be laboring under an erroneous impression, and at the same time possibly indicate in a limited degree the probable field of future activity to which this most potent factor in our commercial and financial progress will be called into requisition. To this end, and in order that the comparison may be sufficiently striking to warrant this review of its development, not only the earlier history should be considered, but the starting point should be from that earlier thought of the application of nature's forces to the uses of man; it would, therefore, seem eminently proper to refer first, to the "NEWTON" of 1680:

The "Newton" of 1680 represents the first efforts of Sir Isaac Newton in his application of steam power to move a vehicle. Newton's conception or application of this force being practically the same as Hero's, but the idea of making it serve as a means of propulsion was his own, and in the odd and curiously shaped vessel, or cauldron, which pretty much resembles a large kettle with a top fastened on so as to prevent steam escaping to the atmosphere. There was an outlet in the rear, operated by a handle from the seat in front, so as to regulate the flow of steam which reacting against the atmosphere propelled the vehicle in the opposite direction. We have here what might be termed the first step toward the modern steam locomotive, and although the device looks very odd and curious, and doubtless was looked upon as the work of a crank, yet the engineering world owes much to Sir Isaac Newton as one of its original engineers.

In 1681, 1683, 1695, 1703, 1707, 1718, 1720, 1737, 1750, 1760 and

1767, were the efforts and experiments of Papin, Moreland, Savary, Newcomen, Potter, Beighton, Neupold, Whitehaven and Murdock, the last having produced a curious looking machine in 1784, which was operated by steam through the medium of a crank axle.

The Newton Steam Locomotive.

About this time Watt appears upon the scene. His principal experiments or field of operations, had been that of pumping water out of mines. His friend, Dr. Robinson, however, had been importuning him to apply steam power to the moving of carriages, and as a result, he and his partner, Bolton, constructed a steam carriage, which they termed a "Fiery Chariot." In 1769 Watt took out a patent on his first rotary engine.

In 1786 William Symington's conception of a steam carriage on three wheels, the front wheel guiding it, was produced, in which for the first time provision was made for carrying passengers in a coach body supported and carried by three wheels.

The "Holland Sail Chariot" of 1765 and Cugnot's steam wagon used for the handling of artillery, and the Murdock's steam wagon in 1784 were fore-runners of the Symington's steam carriages of 1786.

In 1799 Oliver Evans in the United States perfected a high pressure, non-condensing steam engine, which was later applied to stationary use.

In 1800 and 1803 Richard Trevithick produced two steam propelled vehicles; the one in 1803 being a steam carriage for the con-

veyance of passengers. The first one was for a rack rail road, while a similar machine developed by him in 1801 was intended for highways, as was also the steam carriage of 1803. His locomotive of 1803, together with a farther development in 1805 and 1808 were intended for use on tramways. These were operated on the Merthyr Tydvil railway in South Wales, and would propel wagons containing ten tons of iron. This feat was accomplished on a bet of 50 guineas.

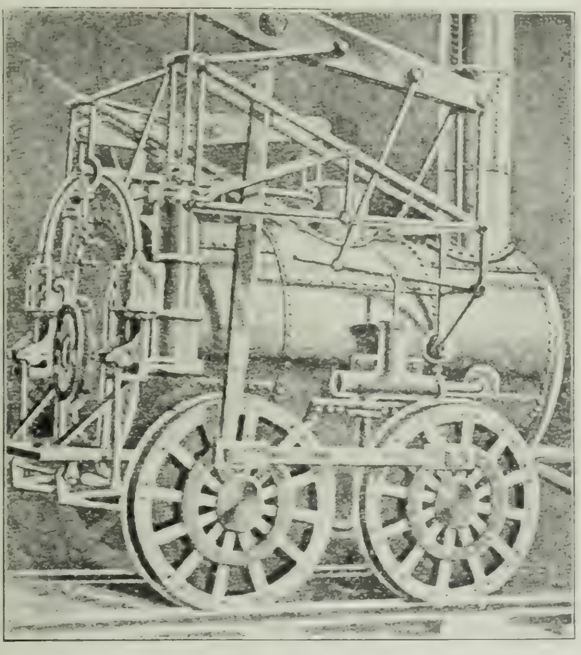
"The Blenkinsop" engine of 1812 was a still farther development of the rack rail device; this was introduced by Christopher Blackett on his tramway at Wylan, which had been altered to suit this type of an engine after the "Trevithick" had finally blown up, after being coaxed, bullied and prodded by the workmen. The experience with the "Blenkinsop" it is said, was almost as disastrous in results as with the "Trevithick," and although it did not blow up, it is claimed that a magnifying glass was required to detect its motion, and that more horses were required to keep it upon the track than would have been necessary to propel the load the engine was supposed to haul. The locomotive finally rolled over the embankment and thus ended its career.

Various experiments, and so called improvements, including the "Brunton" of 1813, which seemed to be on the order of a steam walking man, brings us up to the "Puffing Billy." This was the product of the brain of Mr. Hedley, a new candidate for locomotive honors, who after a successful experiment with his testing carriage, simply a frame work mounted on four wheels, in which he was the first to demonstrate in a practical way the adhesion of smooth wheels to smooth rails, proceeded to build his locomotive, the "Puffing Billy" upon the principle he had proven to be correct. The "Billy" accomplishing with comparative ease the work of ten horses. Hedley finding the weight of this locomotive on four wheels was detrimental to the track, doubled the number of wheels, and thus experimentally produced the first eight wheeler; this not proving satisfactory, however, he returned to the four-wheel style, strengthening the plates of the roadway to meet the requirements.

A number of different types were produced about this time, showing more or less the trend of thought which occupied the minds of engineers of the day. In 1816 Stephenson brought out an engine bearing his name, which was built at the West Moor shops of the Killingworth Colliery, this being his third locomotive, and one in which he introduced steam springs, an arrangement, which proved defective in principle, and was soon abandoned.

Considerable development in steam carriages for public highway use were shown in the inventions of Griffith in 1812 and of James, Burstall, Hill and Gordan in 1824. In 1825, the "Killingworth," a locomotive designed and built by Stephenson, was brought out in which he abandoned entirely the endless chain, substituting outside coupling rods, which connected the front and rear wheels. Steel

springs are first introduced by Stephenson in this engine, together with an innovation in the position of cylinders, thus making the locomotive more compact, in a better form, and getting rid of numerous rods and joints.



An Early English Locomotive, the "Puffing Billy."
(From an old print.)

In 1827 the "Royal George," a four-cylinder locomotive built by the Wilsons of Newcastle, one year prior for the Stockton and Darlington road and which had not proved a success, was rebuilt and re-christened the "Royal George." This engine was so radically changed as to cause much comment, and this was practically the first introduction of the steam blast, and on a well calculated principle. The "Royal George" demonstrated a capacity far ahead of any other locomotive in England at that time.

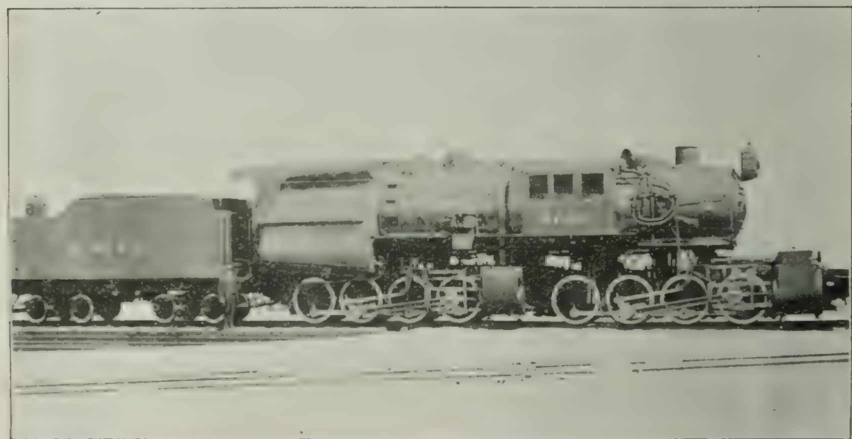
DEVELOPMENT IN AMERICA.

The review thus far, which pertains to the earlier efforts of locomotive designers abroad, brings us up to a period when the introduction of the locomotive was first considered in America, and in order that the difficulties and obstacles which were necessary to be overcome in America by the original promoters of the steam locomotive may be better appreciated, I quote from the report of a Special

Board of Commissioners appointed by the legislature of Pennsylvania in 1831, who were authorized to thoroughly investigate and report upon the practicability of the construction of railways, and the advisability of the State lending any assistance to such a project. A quotation from their report is as follows:

> "While the Board avow themselves favorable to railroads where it is impracticable to construct canals, or under some peculiar circumstance, they can not forbear expressing their opinion that the advocates of railroads generally have over-rated their comparative value; the Board believes that notwithstanding the improvements that have been made in railroads and locomotives it will be found that canals are from two to two and one-half times better than railroads for the purposes required of them by the State of Pennsylania, and they again repeat that their remarks flow from no hostility whatever to railways, for next to canals they are the best means that have been devised to cheapen transportation."

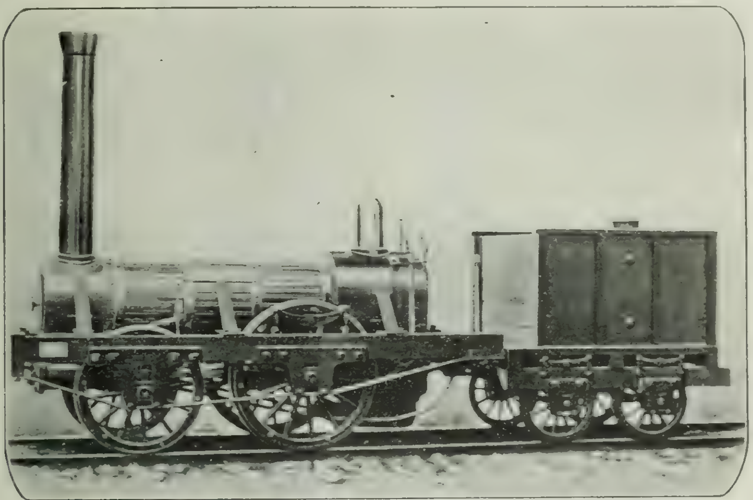
At the time this Report was submitted in 1831, the population of the United States (26 States) was 13,000,000, principally in eight (8) States, with an approximate area of 362,000 square miles, and an average population of twenty-four (24) per square mile. That same area now has population of ninety (90) per square mile, an



100 Ton Locomotive, Erie R. R.

increase of 275 per cent. The State of Pennsylvania was at that time the principal commonwealth, exerting a marked influence over the transportation and commercial interests of the country. The steam locomotive was at that time destined to play that important part in the development and upbuilding of the country, which a history of its progress will clearly show.

The first locomotive of which we have any authentic record in America is the STOURBRIDGE LION. This first steam locomotive used on the American Continent, was brought from England by the Delaware & Hudson Canal Co., and placed in service by Horatio Allen, the celebrated pioneer engineer, near Honesdale, Pa., August, 1829, on what is now a part of the Erie Railroad system. Therefore, the "Erie" holds the proud distinction of having used the first steam locomotive in America on its tracks, and also at present owning and operating the largest steam locomotive in the world. The "Stourbridge Lion" weighed 7 tons, which Mr. Allen, chief engineer, decided was too heavy for their trestles. His report closed its usefulness, it being laid away and gradually dismantled. The pieces were collected together, however, in 1905, and with some additions put together, and it is now in the Smithsonian Institute, Washington, D. C.

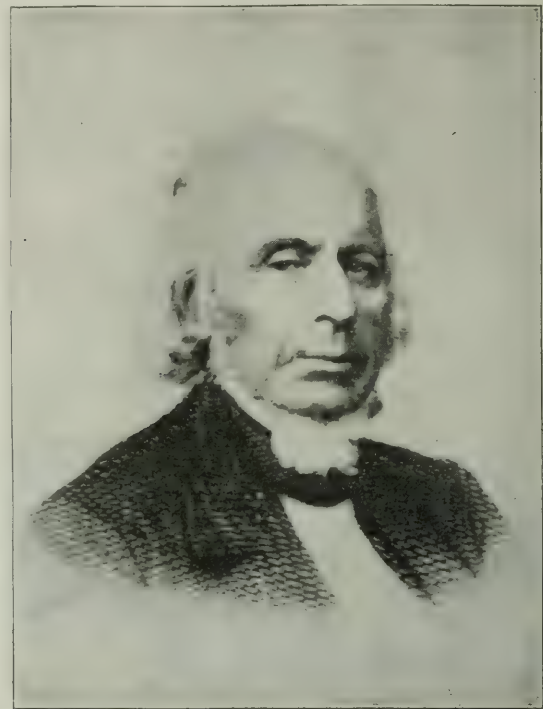


"Old Ironsides."

Concerning "Old Ironsides," the first locomotive built by the Baldwin Locomotive Works at Philadelphia, it would seem eminently proper to give here some facts dating from the completion of its first locomotive. The guiding spirit in this enterprise, and the one to whom credit is due for its existence and the great benefit it has been, and is today in the commercial world, was Mr. Matthias W. Baldwin, whose picture is herewith presented. Mr. Balwwin was born in Elizabeth, N. J., on December 10th, 1795, and learned the trade of a jeweler; in this connection it might be mentioned that the principal locomotive builders of the early days were jewelers or silversmiths.

In 1825 Mr. Baldwin formed a partnership with Mr. David Mason, a machinist, for manufacturing tools and cylinders for printing cali-

cos; their business prospered, and steam power became necessary but the engine they bought for this purpose proved unsatisfactory; Mr. Baldwin designed and built an engine suitable for their requirements, and in a short time it proved so efficient that he received outside orders for additional engines. This engine, the original upright stationary, built in 1830 is still in good order, and is carefully preserved at the Baldwin Works, in Philadelphia.



M. W. Baldwin.

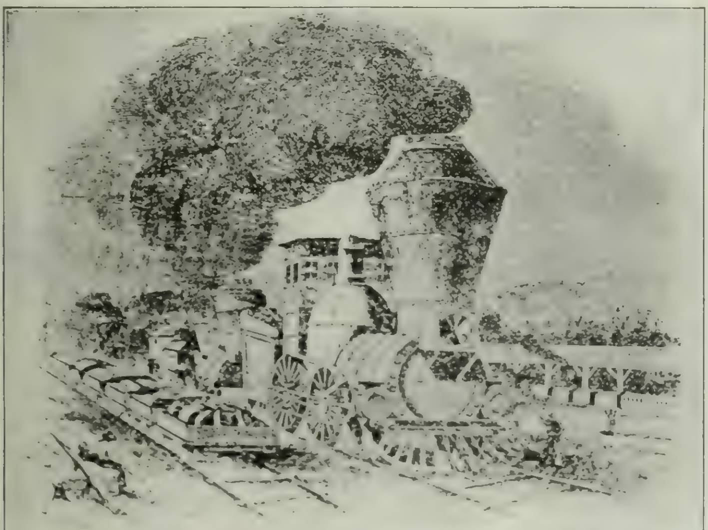
About this time a number of locomotives were imported from England, and one was built at the West Point Foundry in New York in 1831. Mr. Baldwin completed a locomotive for exhibition in a museum, and the success of the model was such that he received his first order for a locomotive from the Philadelphia, Germantown & Norristown R. R. Co. In those early days it was almost a superhuman task to undertake such a work; mechanics were scarce, suitable tools were hard to obtain, cylinders had to be bored with a chisel fastened in a block of wood, while blacksmiths who could weld bars of iron 1½ in. in diameter were extremely few; therefore, Mr. Baldwin, although the designer had to do the work himself, and at the same time, educate such men as assisted him to do their work. The work,

however, was prosecuted to the end, the locomotive was completed, and tried in November, 1832. This was the famous "Old Ironsides" engine, and at the time of its construction, thirty men were employed in the works.

The increased number of engines constructed by the Baldwin Locomotive Works, together with the number of men employed during 1832 to 1907 are as follows:

Year	*No. of Engines Built*	*No. Men Employed*
1832	1	30
1837	40	300
1854	62	500
1855	47	430
1884	429	2,377
1890	946	4,493
1900	1,217	8,208
1906	2,652	17,432

During the period 1832 to 1840 the number of men employed had gradually increased from 30 to 300, and the average weight of these locomotives was between 20,000 and 26,000 pounds, or from 10 to 13 tons. During the period 1842 to 1854 the number of men employed had been increased to 500.



An Early American Locomotive.
(From an old print.)

During the period 1855 to 1860 the principal engines which were constructed were those that are at the present time styled the "American, or Eight-wheel Type" of locomotive. From 1861 to 1865,

which covers the period of our Civil War, trade being very much unsettled, there was, of course, a noticeable falling off in the building of locomotives; following this period of depression, much activity was shown and in 1866 the "Consolidation" type first came into use and the following year the "Mogul."

Mr. Baldwin died in 1866, and aside from having contributed more to the development of the steam locomotive as a complete unit than any other man of his day, he was also the inventor of many of the most important and essential details entering into its construction at that time, and many of which are still retained and in use at the present time.

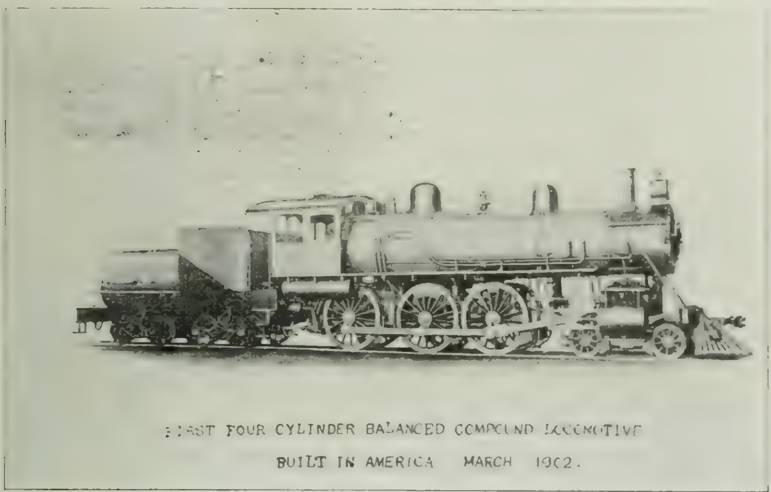
A comparison of the Baldwin Locomotive Works, which consisted of Mr. Baldwin and a few handful of men in 1832, and the Baldwin Locomotive Works at the present day, which organization is based upon an annual output of 2,600 locomotives is as follows:

Number of men employed	19,000
Hours of labor per man per day	10
Principal departments run continuously, hours per day	23
Horse power employed (Steam engines)	12,138
Horse power employed (Oil engines)	4,850
Total horse power	16,988
Number of buildings comprised in the works	47
Acreage comprised in works (Philadelphia)	17.8
Acreage comprised in works (Eddystone)	184.8
Acreage of floor space comprised in buildings	63.2
Number of dynamos for furnishing light (Arc)	16
Number of dynamos for furnishing light (Incandescent)	7
Horse power of electric motors employed for power transmission (aggregate)	14,200
Number of electric lamps in service (Incandescent)	7,000
Number of electric lamps in service (Arc)	951
Number of electric motors in service	1,115
Consumption of coal, in net tons per week, about	3,000
Consumption of iron, in net tons per week, about	5,000
Consumption of other materials, in net tons per week, about	1,460
Approximate value of one year's output	$35,000,000

The American Locomotive Co. are about on the same basis of force and output.

The country in general was enjoying an unusually industrial boom with the incoming of the 20th century. The general prosperity resulting in extra demands for all kinds of transportation; the natural result was a general increase both in the number and capacity of both cars and engines. A special feature or departure, however, from the conventional lines, which had been followed in locomotive construction were noted in improvements; the inventions of Mr. Cor-

nelius Vanderbilt, a mechanical engineer, received much deserved attention from the railroad and engineering world at that time; particularly so in connection with a new type of locomotive tender and fire-box, the first being applied to a ten wheel locomotive built for the Illinois Central R. R. and exhibited at the Pan-American Exposition at Buffalo, New York. The advent of the four cylinder balanced compound engine, however, so closely followed this, that a picture



A Heavy Duty Modern Locomotive.

is herewith presented of the first engine of this latter type built in America. This was the 20,000th locomotive constructed by the Baldwin Locomotive Works, its completion being in February, 1902. The special feature was the balanced principle, together with the previously mentioned cylindrical tank, and fire-box, inventions of Mr. Vanderbilt. The tender design and construction is clearly shown in the illustration.

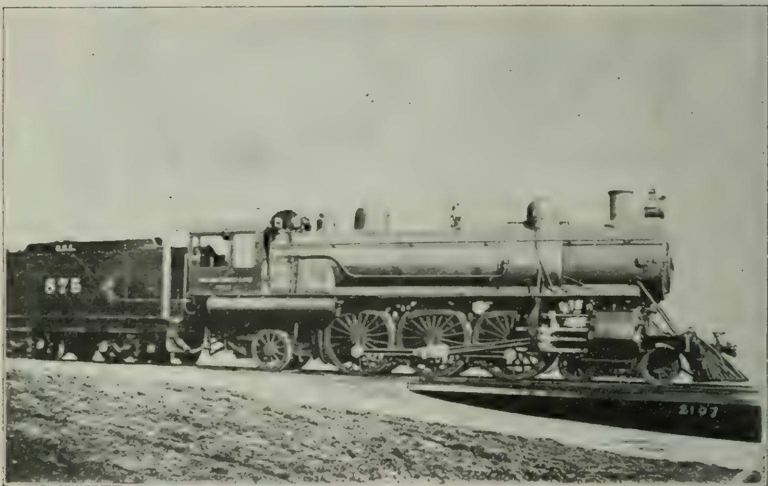
Following the completion of the first balanced compound engine, and the importance attached to its superiority over other types with respect to track maintenance, through the elimination, to a great extent, of the injurious effects of the hammer blow on the rails, its merits seemed to be recognized, and between the time of the construction of the first one, and the present time, there have been built approximately 370 which are in service on American Railways. The principal builder was the Baldwin Locomotive Works, although engines of this kind are also built by the American Locomotive Works, which have given excellent results both in actual service on the road and in testing plants.

One particular railway has in service more of these engines than

any other, namely, the Atchison, Topeka & Santa Fe Ry. which has two hundred and fifty.

The one objectionable feature to this type is the crank axle, which has been regarded by some as its weak point. The materials and methods employed in manufacture however, have improved to such a degree that the axles are now made principally in built-up sections being composed of seven (7) pieces, which are pressed together in a hydraulic machine, the center member being cast steel. This form is heavier than the solid forged type originally used, but is less expensive to make, and should any part require removal, it can be replaced without discarding the entire axle, which seems to be a point in its favor.

Engines of this type have produced some remarkable records, both in speed and efficiency, the most noticeable of these was a balanced



Modern Type of Heavy Passenger Engine.

compound on the Chicago, Burlington & Quincy R .R., which during a series of tests against three single expansion engines, the compound developed 20 per cent more horse power than the other locomotives, making unusual time with a passenger train of twelve cars, weighing with the engine and tender 719 tons. None of the single expansion engines were able to equal this performance and subsequent tests carried out on that road gave about the same results.

Following the completion of certain electric street railway lines and successful experiments with electric locomotives some seventeen years ago, it was predicted by some of the most eminent men of our country, that the steam locomotive's death knell had been sounded. In an authorized interview, one of the leading railway magnates at that time predicted that in twelve or fifteen years the steam locomo-

tive would be pretty generally superseded by the electric locomotive, if not entirely relegated to the scrap heap. The opinion thus expressed was endorsed by many authorities of less prominence, including the daily press and a number of technical papers, with the result, that many were led to believe that the steam locomotive had reached the limit of its usefulness.

There were, however, a number who were not prepared to accept this conclusion; they had heard similar outbursts of enthusiasm on other occasions when some new device was presented with reasonable satisfactory results. Among those who recognized the fallacy of such views was one whom it might have been expected would have accepted the opposite opinion; this was Mr. Frank J. Sprague, whom it might be said, was the father and one of the principal promoters of electric railway transportation in America. The birth of electric railways really occurred at Richmond, Va., in February, 1888, and in an article by Mr. Sprague published in the July issue of the Engineering Magazine, 1895, or about seven years after the completion of the Richmond road, and at a time when the honors showered on Mr. Sprague, and the extravagant prophesies for electricity, and against the steam locomotive would have turned a less conservative man's head, Mr. Sprague among other things, in an able article on

"WILL TRUNK LINES BE OPERATED BY ELECTRICITY?"

very modestly and intelligently reviews the subject, saying among other things:

> "That since the first line has been built, and put in operation, the United States, England, France, Germany and Italy have no less than 700 electric railways, covering 7,000 miles, and representing an investment of $250,000,000."

The very able analysis closed with a prophecy, which time has confirmed in every particular, and which I also quote:

> "Let us lay aside then some of the visionary prophecies concerning electric railways with which probably no one has been more closely identified than myself; no one has greater faith in the electric railway than I, but its future is not in the wholesale destruction of existing great systems. It is in the development of a field of its own with recognized limitations, but of vast possibilities; it will cover such field to the practical exclusion of all other methods of transmitting energy; it will replace the steam locomotive on many suburban and branch lines; it will operate almost all street railway systems and elevated and under-ground roads; it will prove a valuable auxiliary to Trunk Systems, but it has not sounded the death knell for the steam locomotive any more than the dynamo has sounded that of the stationary engine; each has its own legitimate field, and will play its proper part in the needs of all civilization."

There are at the present time entering the city of Chicago some twenty-six (26) Trunk Line railways, operating with steam locomotives. These lines have an aggregate mileage of 90,285 or about 40 per cent of the total mileage in this country; 22,623 locomotives or 40 per cent of the total; 845,106 cars or about 42 per cent of the total, and with a valuation of $5,324,062,000 or a little over 31 per cent of valuation of all railways in the United States, which is placed at $16,936,150,204. These companies operate in the City of Chicago,

Locomotive, Doing Heavy Duty and Smokeless.

with few exceptions, steam locomotives using bituminous coal for fuel, and not infrequently contribute to the evils chargeable to the smoke nuisance, in a manner shown by photographs taken of an engine in service wherein it is assumed that 150 lbs. of coal per sq. foot of grate area per hour is being consumed, with a loss of over 50 per cent of the fuel used. Such favorable results as are at times obtained in locomotive practice may be noted in the next photograph of the same engine, but as you will note, with almost an entire absence of smoke, although the engine in each case is performing the same service.

There are in service in the City of Chicago approximately 650 locomotives, and assuming that each engine consumes 5 tons of coal per day, we have the combustion of 3,250 tons of coal per day; if 1 per cent of this total amount of smoke and soot permanently adheres to buildings, structures, etc., or contributes to the death or destruction of trees, grass, flowers, etc., or to the injury of clothing, people's health, etc., then the steam locomotive, it would seem, stands properly arraigned under a very serious indictment.

However, before rendering a verdict, let us take evidence from both sides, after which we can better determine the proper degree of responsibility.

Heavy Duty Locomotive—emitting much smoke.

The Smoky Atmosphere of Chicago, largely due to Stationary Power Plants.

There are hundreds, and I may say thousands, of chimneys in Chicago daily contributing to the evils of the smoke nuisance, and which no one familiar with the subject will dispute. The public mind, however, has of late been systematically and thoroughly poisoned against corporations, especially railway companies, and on this account the author is inclined to believe that a proper division of responsibility has not been made.

There are approximately 1,129,567 tons per year pass off from chimneys as smoke or soot, and about 1 per cent of this quantity of smoke or soot adheres permanently to buildings, structures, etc.

I would invite your attention to photographs of chimneys wherein practically smokeless combustion is attained, while others show the real origin of the smoke nuisance. A comparison of the relative quantity of fuel used in the city by locomotives and that by stationary plants will show plainly the proportion each contribute. This should, however, be studied in connection with such conditions as surround each.

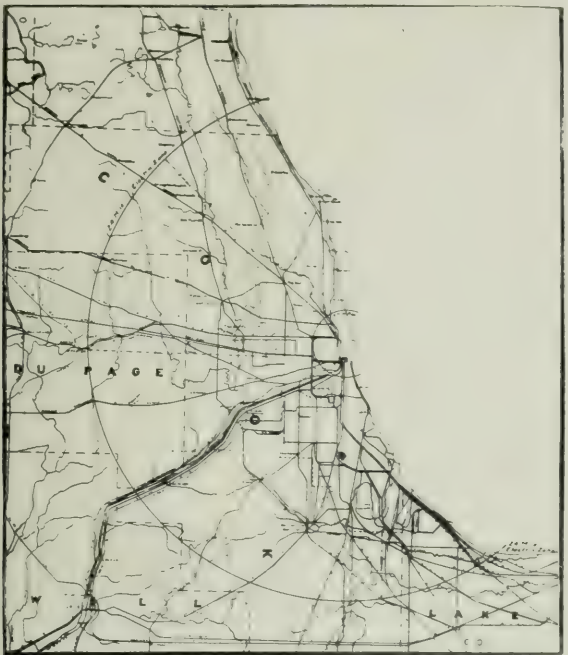
A Smokeless Power Plant in Chicago.

A division of responsibility serves to indicate on whom the burden of relief should rest with respect to abatement, and in this connection, it should be remembered that the schedule of miles, engines, cars and valuation of railways entering Chicago, also applies to many other cities and industrial centers; in other words, many of these lines have small interests here as compared to the sum total of their interests at other points, while the stationary plants are each one a

unit in Chicago's sum total of assets, and in which we have seen that the steam locomotive only contribute 13 per cent of the smoke nuisance.

SUGGESTED REMEDY.

The author suggests consideration of an electric zone and submits tentative plan from which, as will be noted, all steam locomotives using bituminous coal will be, after a certain date, prohibited from entering, in the residence districts, steam locomotives regardless of the kind of fuel used should be reduced to a minimum in numbers, on account of the noise their operation produces.



Suggested 24 mile Electric Zone—within which no steam locomotives are to be used.

In the matter of stationary plants, which seem to be the arch criminals in this indictment, the author would invite attention to the view of a smokeless chimney, which is within range of every day operating conditions, except when first kindling fires, which is a very small fracton of the time. There are may plants, however, which continually produce smoke, and as a step toward an effective and positive remedy, the police power in conjunction with proper engineering talent and practical experts, should regulate those plants, which are to be so designed and constructed as to be operated without emitting smoke; those outside of this qualification should be

given ample time to either put in proper plants, or arrange to secure heat, light, electric current or power from some central plant, to be provided either by the city, or under its supervision, to the end that the smoke nuisance may be effectively and permanently abated without injury to any individual, corporation or industry.

Wonderful progress has been made in the development of electric railways since Mr. Sprague's very conservative prophecy of twelve years ago. A report showing in a general way this development from 1888 to 1902 is as follows:

Companies	987
Mileage	22,576
Cost of road	$2.167,634,077
Number of Employees	140,759,000
Number of Cars	60,290,000
Number of Passengers	4,774,211,904

In addition to this there has been a still greater development since 1902 than recorded prior to that time. Notable among these has been the interest shown by steam railway companies in the matter of electrifying certain sections of their lines.*

Notwithstanding the progress of electric transportation (as above outlined) we should not lose sight of the fact, that the steam locomotive has made greater strides in the matter of increased numbers, together with marked development or refinement both in the manufacture and the operation of the machine. Thus time only tends to confirm the truth of Mr. Sprague's prophesy as to the limits to which electricity and steam are respectively confined.

A very interesting and instructive paper was presented by Messrs. Stillwell and St. Clare Putman at the meeting of the American Institute of Electric Engineers in New York City, January 25th, 1907. Much valuable and interesting data was brought forth and analyzed in a way that could not but arouse much interest in this all absorbing question. Their summing up showed that in a general way the aggregate cost of operation of steam railways of America based on the expenses of 1905 would be reduced about $250,000,000 by changing from steam to electricity. The proposition to electrify all of the steam railways of America is not, in the author's opinion, worthy of consideration, as it would be a practical impossibility from a financial standpoint; he would question the wisdom of undertaking changes of such magnitude when it is easy to determine that in order to realize the economies shown, it would be necessary to stand such unusual losses in other directions, and it would impose additional financial burdens of such magnitude that in the majority of cases bankruptcy would follow.

It would seem, however, a conservative proposition and one that would not impose unnecessary financial burdens on the people, or

*(See Mr. Arnold's Annual Address, January 19th, 1907.)

present any unusual complex engineering problems, to consider the introduction of electricity as a means of transportation in and adjacent to all large cities or commercial centers where the demand or the conditions are similar to those, which have been and are being successfully met in New York City.

Chicago is suffering more from the smoke nuisance than New York ever did. It is also suffering from lack of adequate transportation facilities, and the substitution of electricity for the steam locomotive would provide relief in the matter of transportation; it would contribute relief with respect to the smoke nuisance in proportion to the degree of its responsibility. Both problems are easier of solution in Chicago than they were in New York, presenting no engineering or financial difficulties, which can not be reasonably and satisfactorily met, and it would seem there is really no excuse for farther delay in securing necessary relief in this direction.

In order to illustrate more forcibly the probable future requirements in the matter of transportation let us review the increase in population for some years past, and at the same time observe what conservatively reliable estimates show for the future.

The increase in population in Chicago up to 1892 was about 11.2 per cent, since then, and up to 1901 less than 5 per cent. An average from 1837 to 1892 was 8.6 per cent, in 1902 estimated 2,000,000 population, and at 5 per cent compounded, it is fair to assume the future population will be about as follows:

1910	2,750,000
1920	3,250,000
1930	3,750,000
1940	4,500,000
1950	5,200,000

This is on the conservatively low average of 3 per cent, while if the national and local conditions governing the growth of Chicago were to average in the future exactly as they have in the past, then the population would be at the following rate:

1910	3,500,000
1920	5,500,000
1930	7,750,000
1940	10,250,000
1950	13,000,000

It is hardly reasonable to assume that the latter figures will obtain; under the former figures however, which are very conservative, it is not a great while until Chicago will be a city of 5,000,000 people, and as it is already over-crowded in the business districts with inadequate transportation facilities, which conditions are becoming more aggravated every day, and it is darker than London most of the time from smoke and soot, it is high time that Chicago should wake up not only to its present, but future conditions, and make provision for relief along these lines.

CONCLUSIONS.

This review of the Evolution of the Steam Locomotive, embracing as it has certain correlative features of the instrumentalities of transportation, past, present and future, involving questions of Finance, Engineering and Civic Pride, has for its primary object, the hope of aiding in a limited degree such efforts as has been made or may be under consideration, calculating to improve transportation facilities and beautify the city of Chicago.

On the basis of our present population in the United States, and the transportation facilities to meet our requirements, it is not exaggerated prophesy, but a conservative temperate estimate based on facts that in a few years we will be a nation of 150,000,000 people, and that the Mississippi Valley will be the home of 80,000,000 people.

Should transportation facilities be increased during the next twenty years in proportion to the lowest possible estimate, together with what is at present needed, the rail and water map, may at that time reasonably be assumed to show 400,000 miles of main line and terminal facilities, and several thousand miles of canals and canalized rivers; the latter to include a deep waterway from the Lakes to the Gulf. The increased railway mileage would be approximately 170,000 miles, and the increased number of locomotives necessary for its operation, based on present ratio of miles per engine, would be about 56,000; of this number at least 75 per cent, it is reasonable to assume, will be steam locomotives, which would bring the grand total up to or above the 75,000 mark with possibly 20,000 to 25,000 electric locomotives, or a grand total of 100,000 locomotives.

The cost of the above outlined improvements and additions may be conservatively estimated at $16,000,000,000 or an amount equal to the present valuation of all railway property created or acquired during the seventy-seven years of the period, 1830 to 1907.

Certain prominent railway men have been criticised for their outspoken views as to the country's future requirements in the matter of transportation. In the map shown all present railway lines are eliminated, the heavy lines indicate tentative location of approximately 12,000 miles of broad gauge trunk lines 6½ to 7 ft. gauge, between the principal commercial centers; on these lines trains of special design and construction would handle 8,000 to 10,000 tons without interruption, and thus the prophesy of such men as Mr. E. H. Harriman and Mr. James J. Hill would not only be fully realized, but another distinct epoch in steam locomotive design would be added to its present interesting history.

A glance at the graphic chart not only shows past and present ratios of population, railway mileage, locomotives, cars, etc., but from this it can be seen that predictions as to our future requirements are conservative, and it should be specially noted that Chiacgo, the center and recognized mistress of the vast area tributary thereto, will if she keeps pace with the wheels of progress, profit more than any

other point in the United States from such improvements as must necessarily be made.

Chicago however, can never hope to be even reasonably clean or to enjoy efficient interurban transportation service while she tolerates the smoke nuisance, from 650 steam locomotives and about twelve thousand (12,000) chimneys, of power plants burning bituminous coal.

The electrification of all steam railways, together with similar reforms in all stationary steam plants; or in event of complete success not being practical or feasible, then the city should install power, heating and lighting plants to supply heat, power or light at a reasonable cost to those who either can not or will not install and operate a smokeless plant; this is to the end, that Chicago's well deserved fame as the leading commercial and business city of the Mississippi Valley may be enhanced by taking rank as the most beautiful city.

The author is glad to acknowledge the kind assistance of Messrs. Bion J. Arnold, Frederick A. Delano, F. H. Burnham, Angus Sinclair, Slason Thompson, The Franklin Institute and others.

DISCUSSION.

Mr. P. Junkersfeld M.W.S.E. (Chairman): I feel sure that I voice the views of all those present when I say that we have listened to an exceedingly interesting and profitable paper, and which refers to developments almost incomprehensible for the period included, especially when we think that within the life of a number of men now living locomotives were built by jewelers and watch-makers. Mr. Symons has brought us down to the time when a single locomotive manufacturing company turns out six locomotives per day for every day in the year, including Sundays and holidays.

It might be interesting, in passing, to say that Mr. Hedley, whom he mentions as the inventor of the "puffing Billy," has a great grandson, who today is General Manager of the Interborough system of transportation in New York, which carries something over a million passengers per day. This is simply another illustration of the very rapid advance in transportation within the last century.

Mr. Symons has furthermore told us a few of our faults as residents of Chicago; also some other things which ought to appeal to us, if not to our civic pride, at least to our civic ambitions and possibilities.

Mr. W. L. Abbott, M.W.S.E.: I think, in company with the rest of the audience, I have listened to this paper with considerable uncertainty as to where the author would finally arrive. When he started in I expected to see the end of the locomotive before he finished, but when he did finish I was a little uncertain as to whether steam locomotives were to be replaced by electric, or whether the electric locomotive had reached the zenith of its development as far as replacing the steam locomotive is concerned. If I got one clear idea from the

paper—and there is no criticism on the arrangement of the paper whatever—it is that electric propulsion on railways should replace steam in densely populated centers, only like that, for instance, within 25 miles of Chicago.

Then the author goes on to show that we are within an epoch of great increase in population, wherein the railway business of the country, and particularly of the Mississippi Valley, will undergo great development, and if the electric locomotive has any mission other than that of smoke abatement, I cannot understand why it will not have its place all over this Mississippi Valley, which the author says will be populated with more than the present entire population of the United States.

The limitation to the general adoption of electric haulage is the number of trains per hour, you might say, on the road. If, with this increase of business in population, there comes a corresponding, or even greater, increase of railway business, that objection will be met.

The matter of transmission of electrical energy is another drawback in the way of substitution of electric for steam transportation. This is being gradually and rapidly overcome. Long distance electric transmission is stretching out its lines further and further every year; voltages are being raised; insulation is being improved; aerial lines are being more substantially built, and I consider that the matter of extending and maintaining aerial lines for the transmission of power is now no more of a problem than was the maintenance of telegraph lines at the time the telegraph system was first introduced. With the extension of power transmission to distances, we will say, of 200 to 300 miles, it will readily be possible to locate power houses at the mines and transmit energy all over the Mississippi Valley and all over the country east of the Alleghenies—at least nearly so—without transporting coal on railroads. I do not know what fraction of the freight business of the railway companies now consists in hauling their own coal, but it must be considerable, and to relieve the railway companies from this amount of tonnage would make their equipment at once available for more profitable business, since the haulage of coal, is about the cheapest work which they do.

The coal economy of locomotives, while it has been considerably improved by the introduction of the compound locomotive, is necessarily limited, and must always be far below that possible with power houses equipped with large boilers and large steam turbines. Power houses are able to use an inferior quality of coal at the mine which is not suitable for any other business. Railways require the best grade of coal. If the railways could obtain their fuel at a price, we will say, about one-third of what they are now paying per ton mile, I presume the saving would be equal to the money which is paid out in dividends. Looked at from these points of view, I cannot but consider that the prospect for the permanency of the steam locomotive is not bright, and the passing of the steam locomotive may be nearer than the author would have us believe.

Referring to the smoke problem, particularly within the city of Chicago. The author says, in effect, that because the locomotives burn about 15 per cent of the coal burned in the city, they make only 15 per cent of the smoke. It has been my observation for sometime that the amount of smoke emitted by a plant has little, if any relation to the diameter of the chimney. A stack burning a bushel of coal an hour may make more smoke than a stack whose furnaces consume several tons. I cannot agree with him in the statement that the locomotives have made very little impression upon the general dirty condition of the atmosphere of the city.

Mr. Junkersfeld: Following the thought which Mr. Abbott and the author have expressed, it might be interesting to note that the New York Central Railroad Company is operating all its passenger trains within the electric zone with about 10,000 k.w. of power-house demand. Using that as a basis, it has been calculated roughly that passenger trains within the 24-mile zone, as shown by the author, could be operated with something like 50,000 k.w. That means that all the passenger trains within that zone could be operated by three or four units in a large modern power house.

Mr. J. N. Hatch, M.W.S.E.: The author has given us a very interesting forecast of what will be the demands for transportation in the future, with the great increase in population which he predicts. But the implication seems to me to be that the steam locomotive will continue to increase and will at that future date, which he has considered, bear much the same preponderance of importance in transportation which it holds today. As to the truth of this prediction I have very grave doubts, if a curve were drawn showing the relative importance of locomotives as a factor in the transportation problem of the country, I am not sure but we have already reached the highest point of that curve. I believe that the importance of the locomotive as an economic factor in this country has already reached its zenith. The question of whether the railroads will change over to electricity or not, is bringing out some interesting discussion. I think the problem hinges, not so much on whether or not they can afford to electrify or whether they are willing to go to the expense, as on the question as to whether they can afford *not* to electrify. This question it seems to me hinges on whether or not the electric railway will be profitable. If electric railways are profitable, the railroads can do as they please about changing over; if they do not, electric railways will be built, and in the last analysis, the railroads will have no choice in the matter; it will be change or go out of business.

Another thing which it seems to me is going to have a great bearing on this is the convenience of the electric railway over the steam road. It will be only a short time now until electric roads will be in operation from Chicago through to Cincinnati, Louisville, Detroit, and other such cities, and it will be but a few years until almost all the present one-night runs of the steam locomotive will be made by the

electric railways. At the present time a great many of those steam roads kill time all night in order not to arrive at the destination until a reasonable time in the morning. This is especially true of such points as Detroit and Indianapolis. There is no question but that the electric roads, even in the present state of the art, can make such runs in one night, and if they put on sleeping cars and become popular, they stand a good chance of taking away all sleeping car business from the steam roads. It would not be at all surprising to me if sleeping cars run on the electric railways—especially the one-night runs—would drive the steam car, for that distance, practically out of business.

Several years ago I worked on the Third Avenue cable line in New York City, and they spent a tremendous amount of money putting in the cable, but in five years' time they did not hesitate to change that over to an electric line. In Pittsburg and Cleveland they blew out all the cable work with dynamite, and put in electric lines. Certainly these cable roads cost as much as steam roads and if the cable companies did hesitate to do a thing like that when they found they had to, I do not see but that it is simply a question whether or not the electric roads will pay, that will decide the matter.

Mr. A. Bement, M.W.S.E. (by letter): Mr. Symons has raised the question of responsibility for smoke emission. It is a very interesting subject and one well entitled to more careful consideration than it has thus far received. It is and has been the practice to attach the entire blame to the individual firm or corporation owning the smoky chimney, and it is against this class and no other that legislation is directed, when as a matter of fact the furnace apparatus is designed and built by others. It is also true that the owner is compelled to depend upon the services of members of the community, who in the capacity of firemen, operate the furnace; thus we have a situation wherein an architect, a consulting engineer, a manufacturer of furnaces, and a furnace operator as well as the owner of the chimney, have contributed to the production of smoke, but of these, four classes are immune, the owner taking the blame and punishment for all of them. Under present conditions, of course, there is no other way, and while the owner is in very large measure an innocent victim of circumstances, yet it is through him that these other people are reached in only a feeble and indirect manner; thus the smoke suppression campaign naturally works at rather a low efficiency owing to the high resistance offered by the medium through which its efforts are expended.

Strange as it may seem, the most important results in the way of smoke elimination have come through changes which have been due to other causes rather than that of the elimination of smoke itself. For example, a factory will go on for years using apparatus that not only wastes a large amount of money but pollutes the atmosphere, owing to incomplete combustion, until it is desirable to install a new

power plant, at which time, often by accident or the result of personal prejudice, either a Sterling with its long ignition arch or a Heine boiler with a tile roof are purchased and fitted with chain grate stokers, with the result that the plant may become a smokeless one.

As far as locomotive smoke is concerned, it is probable that no decided cure will be effected until electrification of that portion of the various railroads which enter the city is accomplished. Thus electricity which has done so much up to the present time in eliminating the smoky chimney, will be an increasingly important factor in the future, with the result that the installation of small steam plants will become still less frequent.

CLOSURE.

Mr. Symons: The remarks of Messrs. Abbott and Hatch are very much to the point, and bring out some good features bearing on certain phases of steam and electric railways. I regret that other speakers were not in attendance to discuss the question from other standpoints, and bring out additional information, which it was contemplated would be of much value.

Referring to the percentage, or proportion of smoke emitted by locomotives as compared to the total, I will say, by way of explanation, that the number of locomotives used in my calculation was the number that is reported as being assigned to service in the Chicago district. Included in these are switching and work-train engines; many of them being outside the city limits, a portion, or all of the time. There are a certain number of engines termed "road engines" taking trains from passenger depots, or freight yards, that contribute some to the smoke nuisance, and I assumed for the purpose of my calculation that the number of road engines, which enter the city each day to either deliver, or take out incoming or outgoing trains, would about off-set the number of switch engines assigned to the Chicago district, which were outside of the city, and thus did not contribute to the smoke nuisance. Taking this number of locomotives as a basis, I then assumed they would consume 5 tons of coal per day per engine, while in practice they do not use this amount. The records from some of the most prominent lines running out of Chicago, having in service the largest modern switch engines, show that these engines burn on an average, less than 4 tons of coal per day; therefore I think that in my calculation a degree of liberality was shown, which would more than off-set such credits as might be due to chimneys of stationary plants, which are smokeless. In the absence of this explanation, however, I think Mr. Abbott's criticism was quite proper, and to the point.

In the matter of extensions of electric railways referred to both by Messrs. Hatch and Abbott, I think it is quite true, that lines will be extended more in future than they have in the past until the entire Mississippi Valley from the Rocky Mountains to the Alleghenys will

be gridironed with electric lines. The question of transmission of energy has, I think, been satisfactorily solved. The figures quoted, however, as to our probable future requirements in the matter of steam and electric railways were arrived at by taking into consideration all of the features mentioned by the previous speakers, favorable to the development of the electric railway. It also took into consideration our increased population for the next twenty years, and the necessity of meeting their views and actual needs in the matter of transportation, and while I assumed the development of the electric railway would be as great as that anticipated by others, I have not reached the conclusion, and am not prepared to admit, that this increased electric development will in any manner interfere with the development of steam railways into new countries; neither do I think it will result in driving any of the present steam railways out of business in the older settled communities. Take for instance, present day conditions in Ohio, Indiana and portions of Illinois. Indianapolis is today considered as being the best provided with transportation facilities of any point in the civilized world, there being a veritable net work of electric railways diverging from, or entering, that city, and connecting with prominent cities within a radius of 200 miles. It is a fact, however, that during the development of this net work of electric railways, that the steam railways in operation in this same territory have added enormously to their equipment, both in the number of freight and passenger cars and locomotives. There are more steam locomotives in service today on the lines most closely paralleled by these electric railways than there were before the elctric railway was constructed, and the steam locomotives are, as a rule, about twice the capacity of those in service twenty years ago, which is equivalent to about four fold increase in steam transportation facilities. Our increased population throughout the country will result in a repetition of these conditions over almost the entire area between the Alleghenys and the Rocky Mountains, and in addition to this, there must necessarily be thousands of miles of canals and canalized rivers providing for transportation of low grade freights, such as coal, ore, lumber, etc.

We have ceased to be a frontier country, except in its application to some of the most remote districts that are still unsettled, and in those districts the steam locomotive will continue in the future, as in the past to be the "pioneer," which will penetrate, open up, develop and populate these unsettled areas, after which the electric lines will come just as it has in the older states and communities.

It was only a few years ago that the merchant or tradsman went to market twice per year to purchase goods for his customers; today through the middle states where the transportation facilities above mentioned exist, he goes every week and sometimes oftener, purchasing goods in small quantities and which he frequently insists on having delivered to him the next morning.

This furnishes business for the electric railway and for the steam railway combined, and with several hundred thousand tradesmen in the Mississippi Valley with several million inhabitants depending upon them, it can easily be seen that the construction of both electric and steam railways will not likely be on a sufficiently broad, or liberal scale to meet the requirements of the people, and that there is absolutely no danger at the present time of one injuring the other, as they will both probably fall short of meeting the requirements in many cases. The only field of probable controversy is in large cities, where it is not a question of supremacy or of a survival of one as against the other from a financial standpoint, but a question of meeting a condition in which steam locomotives are unsuited and electric propulsion is not only desirable, but necessary. The question of relative cost is a secondary one. Therefore, to provide facilities for a nation of 150,000,000 people, which is close at hand, (and we have the official statement of the census bureau in Washington that we will be a nation of 900,000,000 people in 134 years) we will have to commence building new steam railways, provide second, third and fourth tracks for existing lines, possibly construct ten to twelve thousand miles of broad gauge steam railways with specially designed equipment, and increase the mileage of canals, canalized rivers, including a twenty foot waterway from the Lakes to the Gulf. This work should be prosecuted as fast as funds and labor can be provided. The electrification of trunk lines to be considered for terminal facilities at all large cities like New York, Chicago, St. Louis, Pittsburg, Cincinnati, Cleveland, Buffalo, etc. This, not only with a view of eliminating the smoke nuisance, but in order to provide more efficient train movements within the city limits.

It is not extravagant to prophesy that some of the present complex problems of transportation, and many future ones, may find solution in improved and increased instrumentalities of transportation of such a character that the purchasers' requirements may be met on a basis more in harmony with the service rendered than at present. Passengers of limited means, and not in haste, should not be required to pay the same rate as those of wealth, who demand, and willingly pay for the service of high speed and luxurious trains; the same principle may be well considered with respect to freight movements. In the years to come it is fair to assume there will be provided combined facilities to handle the commerce of the nation that will embrace waterways and additional tracks for low grade traffic, electric lines and high speed tracks for fast freight and passenger trains, and electric locomotives in most all large cities, and in many cases plying between large centers of population.

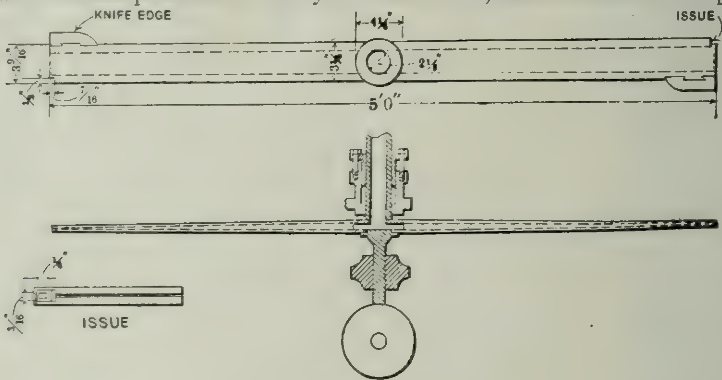
STEAM TURBINE DEVELOPMENT

Prof. J. C. Thorpe, M.W.S.E.

Presented May 6, 1908.

So much has been written during the past few years relating to the various phases of steam turbine engineering that one is confronted by a Herculean task, who proposes to present anything particularly new to an assembly of engineers, many of whom have been closely in touch with steam turbine development and operation. Thus, it was without a particular intention of presenting new thoughts that this paper was prepared, but rather of gathering together from various sources some of the facts developed during recent years and compiling them in convenient form for consideration.

Among the noteworthy facts that impresses itself upon the mind of the investigator of the development of steam turbines is the very close resemblance of the earliest types to many of the present day machines that are proving such efficient prime movers in our power stations of both large and small capacity. In order to observe this fact, let us turn aside from the limitations of our subject for a short period to consider some of the more prominent inventions of the early day. Professor Storm Bull, now deceased, in the presentation of his paper before this society in June, 1905, noted the beginning of steam turbine practice in the year 120 B. C., when Hero's Aeolpile



Avery Reaction Wheel.

Fig. 1.

was operated. In this machine we note the purely re-active steam turbine. In 1831, in Buffalo, New York, Mr. William Avery constructed and operated what is known as the Avery steam turbine, which was similar to the old Hero engine, a reaction turbine in the strictest sense. Steam enters the hollow shaft, passes to the ends

of the hollow arms, where it issues at an enormous velocity. This machine for some time operated in a saw mill in or near Buffalo where it displaced a reciprocating engine. The excessive air friction and the erosion by the wet steam necessitated frequent and expensive repairs which eventually caused its abandonment.

In 1629, an Italian inventor, Giovanni Branca, published a book in Rome entitled "The Machine." In this book Branca described "The Branca Impulse Steam Turbine." In this machine a jet of steam is made to issue from the mouth of a negro's head, serving as a steam generator and impinge against the blades of a large wheel geared to a small stamp mill. This was the beginning of the now very popu-

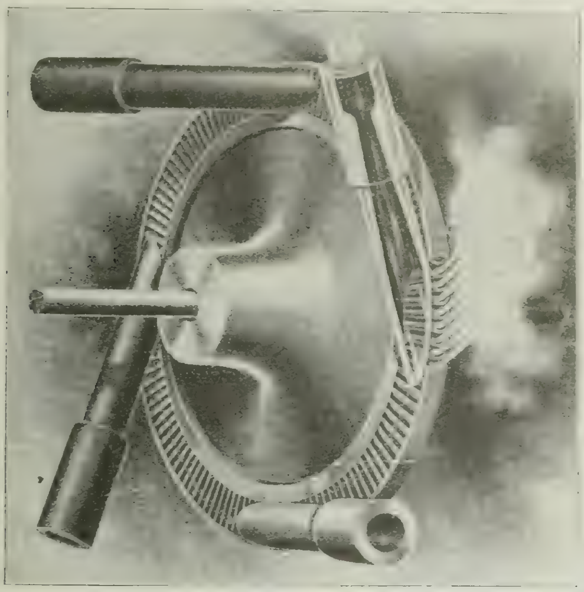


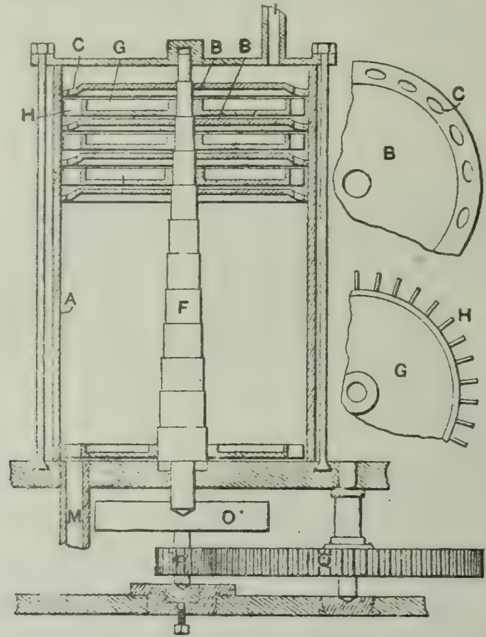
Fig. 2. The De Laval Turbine

lar impulse type of turbine. In 1884, De Laval first published the results of some of his earlier experiments and applied for patents on the De Laval turbine. This simple impulse turbine is one of the popular types today for small powers and it is not difficult to trace the suggestions of the Branca turbine through history to this highly efficient machine.

Many of the inventions of recent years have been as visionary and impracticable as the inventions of Hero and Branca. However, there are records available of a few inventions which were the forerunners of the successful turbines of today, and which the writer believes would be of interest to consider at this time.

It was early understood that the enormous steam velocity and re-

ulting peripheral speeds of the simple reaction and impulse wheels presented a great obstacle which must be overcome before the steam turbine would be of any considerable value, industrially. In 1827, Real and Pichon, Frenchmen, patented a compound impulse turbine that attempted the desired speed reduction by distributing the drop in pressure through a number of stages.



Real and Pichon Compound Turbine.
Fig. 3.

Experiments upon the flow of steam through variously shaped converging and diverging nozzles occupied the attention of many steam turbine experimentors. In 1838, one, Leroy, first published the results of such experiments and applied for patents on the Leroy reaction wheels.

There were special applications of the Avery reaction wheel mentioned above. The results of Leroy's experiments have been repeatedly verified by investigators during recent years.

It is interesting to note the numerous inventions of the earlier day failed to take any account of the increasing volume resulting from the drop in pressure from stage to stage, although the desirability of compounding was early understood as has been shown.

In 1848, United States patents were issued to one, Wilson, who occupies a prominent place among early steam turbine investigators. His most interesting and valuable invention immediately suggests the Parsons type and may be said to be the forerunner of that most ex-

cellent machine. Wilson was the first inventor to establish a claim based upon the increasing volume resulting from the distributed pressure drop.

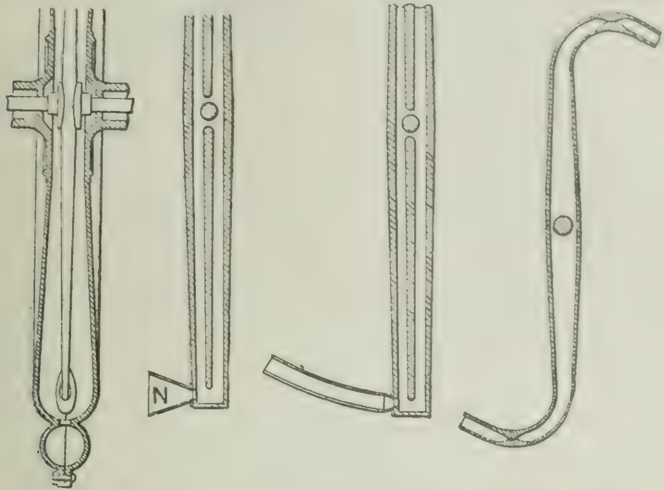
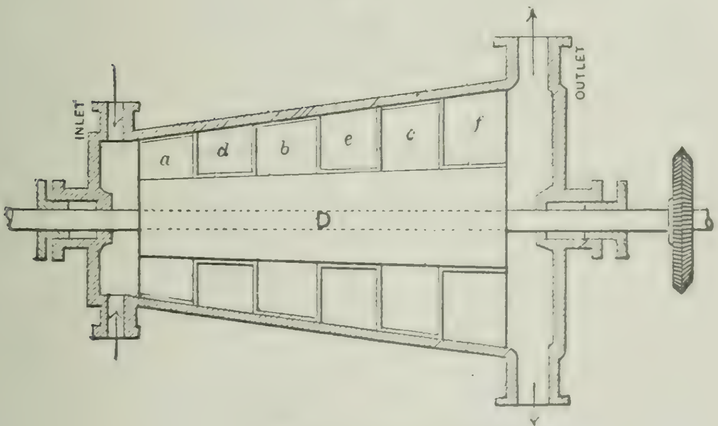


Fig. 3. **Fig. 4.** **Fig. 5**

LeRoy's Reaction Wheels.

Fig. 4

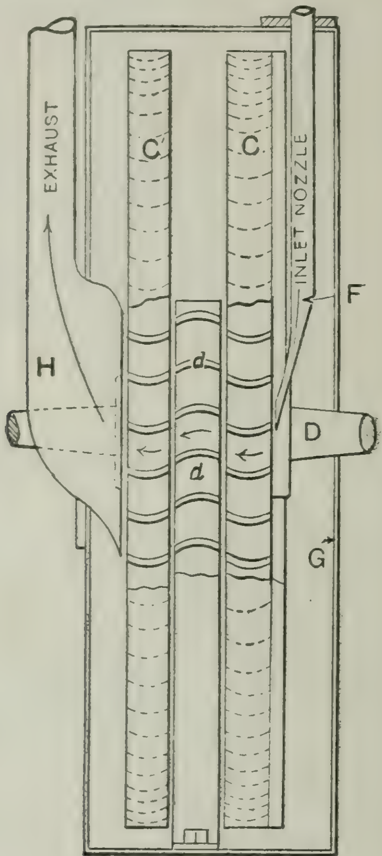


Wilson's Compound Turbine.

Fig. 5.

In 1858, patents were secured by John and Ezra Hartman, the similarity of which machine to the modern Curtis turbine is immediately noticeable. The steam is expanded in the inlet nozzle and impinges alternately upon revolving and stationary blades, no attempt being

made to increase the velocity or reduce the pressure while passing through the sets of blades.



Hartman's Compound Impulse Turbine.

Fig. 6.

Another interesting invention in this connection is that of Moorhouse, in 1877. This machine, very similar to the present Hamilton-Holsworth turbine, built by Hooven, Owens and Rentschler, Hamilton, Ohio, which is of the impulse multi-stage type.

In 1885, patents were issued in several countries, covering the invention of a compound balanced reaction turbine, to Hon. C. A. Parsons, whose name from this date has been inseparably linked with steam turbine development. His first invention, Fig. 7, is very interesting, showing Parson's conception of the importance of the prin-

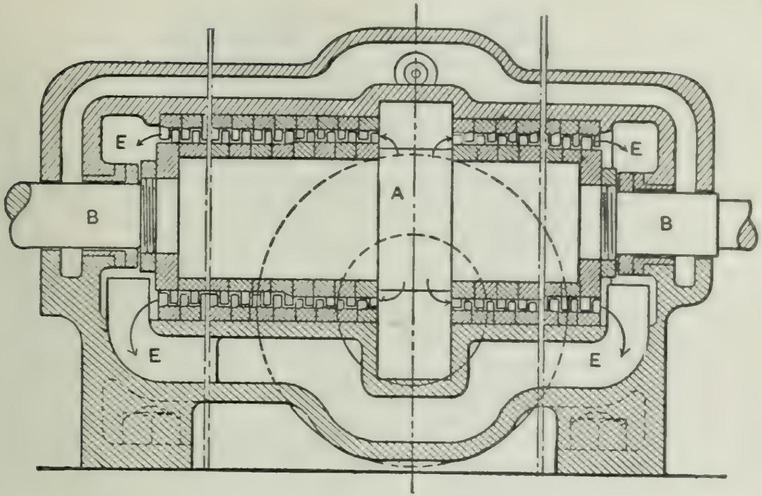


Fig. 7.

ciples of compounding and of the lateral balancing of horizontal machines. Among the other prominent features of this machine still approved and applied in the most modern design, are elasticity of bearings and forced lubrication. It may be said that Parsons was the first inventor to place the steam turbine on a commercial basis.

In 1889, De Laval, whose name is closely linked with that of Parsons in steam turbine development, secured his patents on the present expanding nozzle used with the De Laval machines. A patent on the expanding nozzle as applied to injectors had been issued twenty-five years before, but it remained for De Laval to apply it to the impulse turbine.

Much experimenting has been carried on and many patents secured quite recently upon various applications of Pelton Wheel buckets to steam turbines. The earliest patents issued in this connection were dated 1894, when J. T. McElroy and Professor A. Rateau received American and English rights, respectively. Defects in the design and construction of McElroy's turbine prevented its commercial application, but the simple impulse machine with Pelton buckets, of Rateau, attained some prominence before it was superceded by the multi-stage type. A general view of the rotor of the simple Rateau turbine, is shown in Fig. 8.

In view of the fact that the application of Pelton wheel buckets is the subject of much discussion and experimentation, it will be interesting to note the arguments presented in favor of their use. These arguments are presented in the light of objections to ordinary blading, which are:*

*"Steam Turbines," by L. G. French.

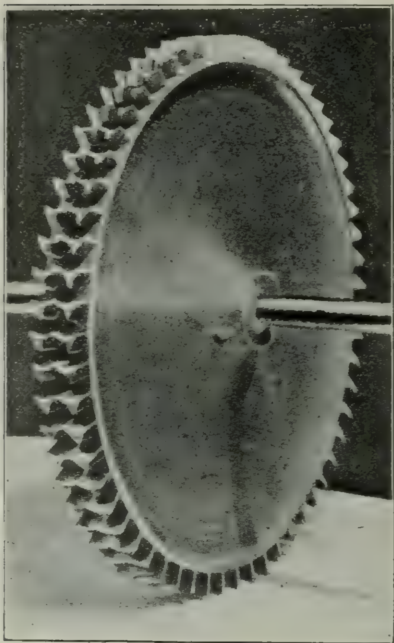


Fig. 8.

1. Increases the number of buckets at least five times.
2. Distorts the angle of reaction from 15 to 30 degrees in order to secure clearance.
3. Makes necessary the side application of the steam jet, thus increasing lateral stress and vibration.
4. Augments fluid friction.

Among the other turbines of more or less prominence, both in this country and abroad that use the Pelton bucket are, the Riedler-Stumpf of Berlin, the Zoelly and the Kerr.

The Riedler-Stumpf wheels were invented by Professor Stumpf, who was assisted in their development by Professor Riedler. A wheel and nozzle ring of this machine is shown in Fig. 9. It will be noticed that the nozzles, which are of the De Laval general type, extend completely around the periphery of the nozzle ring. Subsequent patents covered the return guides that were used to redirect the steam issuing from the wheel a second time upon the blades.

The first patents on the Zoelly turbine were taken out by Heinrich Zoelly in 1900. They set forth in particular the construction of a multi-stage turbine, with one rotor only, in each stage and a particular construction of the wheel disks. The arms, if they may be called such, were machined for a considerable part of their length and ended in the Pelton buckets, as shown in Fig. 10. The larger Zoelly

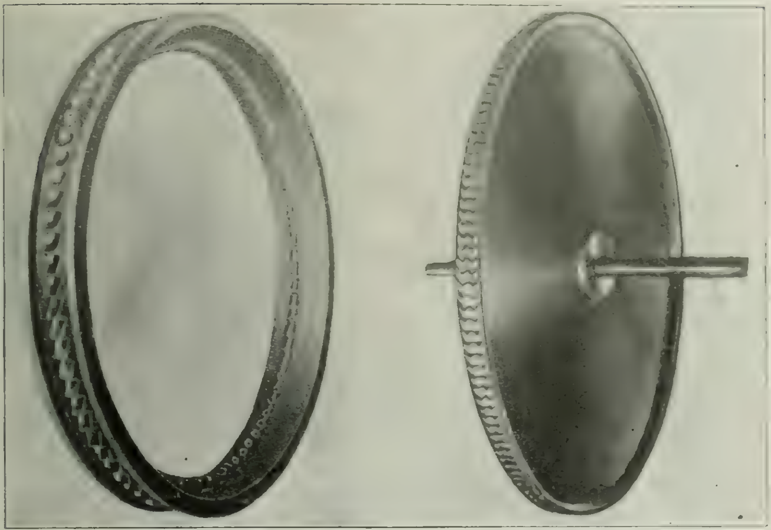


Fig. 9.

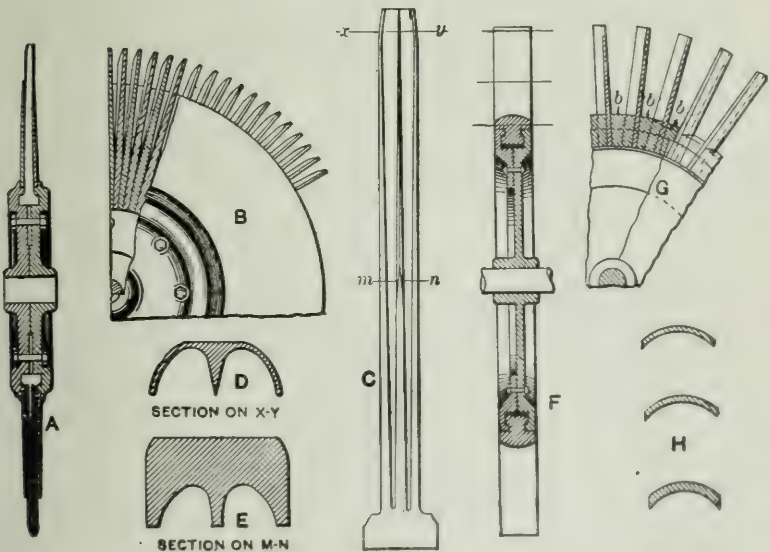


Fig. 10.

turbines are built in two sections, a high pressure and low pressure section, the steam passing from the high pressure to the low pressure side through steam passage in the turbine base.

The Kerr turbine is built by the Kerr Steam Turbine Company of Wellsville, New York. It is an interesting machine in the field of small non-condensing units of smaller powers.

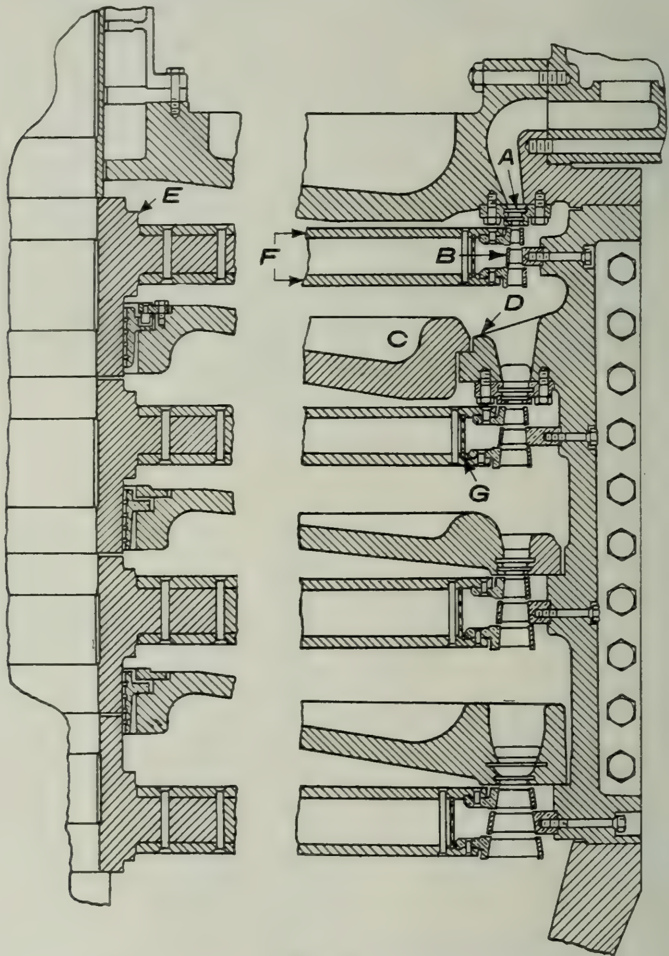


Fig. 11.

In 1896, Mr. C. G. Curtis took out a group of patents covering the important principles of construction of the Curtis Turbine, manufactured by the General Electric Co., of Schenectady, New York. The most significant feature of Mr. Curtis' claims was the application of the system of diverging nozzles with the compound wheel. Other

inventors had applied the results of expansion that could take place only in a diverging nozzle but no invention had been previously made of the apparatus itself. In Fig. 11, is shown the present preferred arrangement of nozzle and moving and stationary or intermediate blades.

In the preceding discussion, the more important inventions that have influenced turbine development have been considered. That the principal difficulties in design and construction were early recognized is very apparent. From the earlier days, designers have endeavored to reduce the energy losses to a minimum and it is this desire that inspires present day designers who have brought the steam turbine to the prominent place which it occupies in the list of prime movers. The energy losses, mentioned with their approximate average values, may be classified as follows:

1. Friction between the steam and the metallic surfaces, both stationary and moving,	10%	12%
2. Friction due to eddy currents,	5%	7%
3. Resistance to the rotation of moving parts in the atmosphere of steam, called "windage."	6%	8%
4. Mechanical friction in journal bearings, glands, stuffing boxes, etc.	5%	10%
5. Leakage through clearance spaces, glands, etc.	3%	7%
6. Radiation loss, 7. Residual velocity in exhaust,	4%	8%

The constant striving to minimize these losses has resulted in improved methods of governing, special devices for cutting, shaping and spacing the turbine blades, exhaustive experimentation relating to the flow of steam through nozzles and orifices, the development of high pressure lubricating systems and high temperature packing, and in the development of remarkably efficient condensing equipment, particularly in units of large capacity.

STEAM TURBINE PERFORMANCE.

A consideration of some particular installations with the results of steam economy tests will indicate the measure of success that has attended the recent development of steam turbine practice.

In 1902, after very careful consideration of the steam turbine problem, the then Commonwealth Electric Co., of Chicago, purchased the first 5,000 kw. machine that was built. Just previous to this, the Westinghouse Company had taken the contract to build a 1,500 kw. unit which was installed in the plant of the Hartford Electric Light Co., of Hartford, Conn. It is worthy to note that the turbine, Unit No. 1 in the Fisk Street Station of the present Commonwealth Edison Co. was the result of the first effort that had ever been made in this country to build a machine of this type larger than 600 kw. The 600 kw. turbine mentioned was a two stage, horizontal Curtis ma

chine installed in 1901 in the shops of the General Electric Co., at Schenectady, N. Y. It is a compliment to the engineers and management of the General Electric Co., who built and installed this first larger unit, that they planned and built so well and confidently at that time. We doubt not that, in the light of more recent designs, this first large turbine to be installed in this country fails to nourish the pride of its designer, and yet, all must agree that the undertaking at that time was very meritorious.

The writer has been privileged during the past two years to conduct tests on three of the units in the Fisk Street Station, Commonwealth Edison Co. These units with the approximate dates of installation and their respective kw. ratings are as follows:

Unit No. 1, first operated September, 1902, normal capacity, 5,000 kw.

Unit No. 4, first operated September, 1905, normal capacity, 5,000 kw.

Unit No. 8, first operated December, 1905, normal capacity, 8,000 kw.

A brief summary of the results of these tests is presented in the following table:

OPERATING CONDITIONS.

Comparative Results—Best Performance.

1.	Nominal Rating of machine, kws....	5000	5000	8000
2	Load—Gross output, kws.........	6137	5970	10156
3.	Ditto—per cent normal rating	1.25	1.20	1.25
4.	Water rate—observed kw-hr.......	23.85	16.56	12.94
5.	Ditto—corrected for .... "Contract Conditions"	23.94	16.72	13.07
6.	Water Rate—observed e.h.p.-hr....	17.89	12.42	9.71
7.	Ditto, corrected for .... "Contract Conditions"..........	17.96	12.54	9.80
8.	Initial Pressure, pounds...........	176.6	174.0	176.0
9.	Vacuum observed, inches	28.10	28.0	29.17
10.	Vacuum, 30 in. barometer, inches ..	28.52	28.30	29.50
11.	Superheat—Deg. Fahr.	139.0	184.0	147.0
12.	First stage pressure, lb gage.......	5.66	34.8	46.7
13.	Normal speed, r.p.m.	500	500	750

The accompanying curves, Fig. 12, present the relative steam economies of these three units in a very interesting manner. It will be seen that the scale of the vertical ordinate, representing "Water Rate," is continuous, thus giving a direct comparison of the units, all values of the steam economy having been reduced to the basis

1. A considerable condenser leakage necessitated a correction in the steam flow of Turbine No. 1.

2. Results of tests of No. 4 taken from Report of Tests of Turbine No. 4, J. C. Thorpe to Mr. F. Sargent, April 24, 1906.

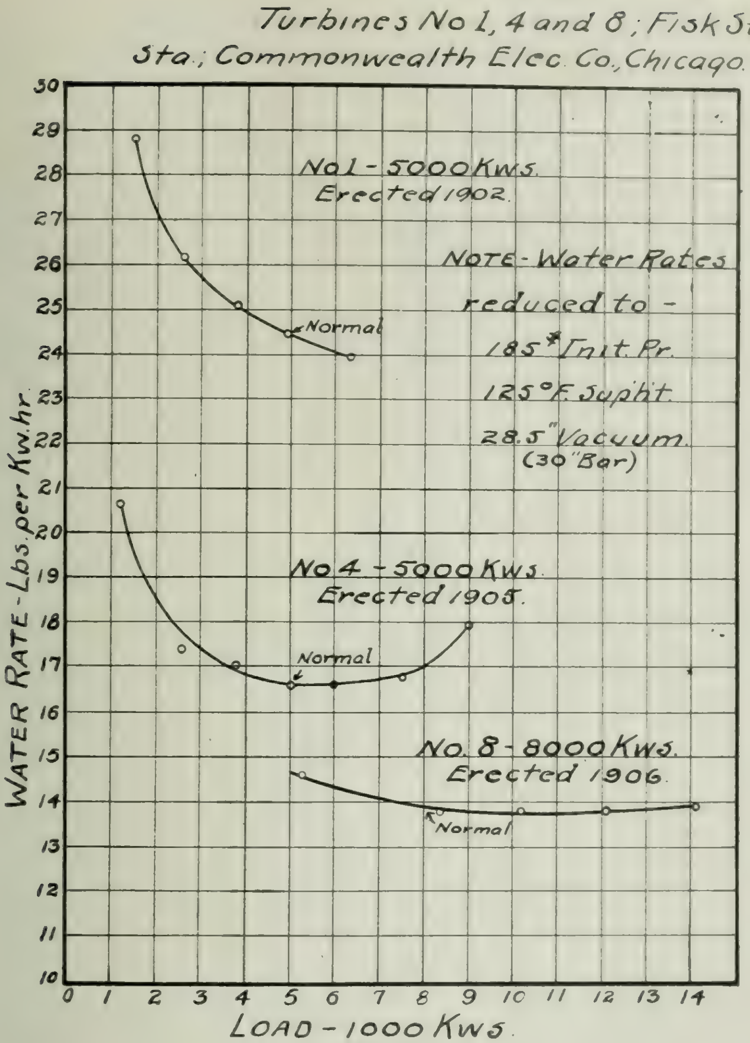


Fig. 12.

indicated. Another notable feature is the flatness of the load curve for Unit No. 8. It is noticeable in No. 4, but less markedly and the tendency to give a wide range of economy with a considerable range of load is hardly perceptible in the first unit. It is difficult to say what the results would have been in the latter case had the load been increased to 75% overload. as in the case of No. 8. These curves serve better than words to illustrate the remarkable development in the design and operation of large turbine units of this type during the past five years.

The curve AA in Fig. 13 represents the steam economy of the 500 kw. horizontal Curtis turbine mentioned above, and curve BB, the economy of a 600 kw. Curtis turbine, erected in the station of the Massachusetts Electric Co. at Newport, R. I. The test was conducted by Mr. George H. Barrus and appears in a bulletin issued by the General Electric Co. The difference in water rate is probably due to the fact that the 500 kw. machine was tested with a service load which fluctuated greatly during each trial; whereas, the test of the 600 kw. machine was a shop test, when more nearly absolute control was had over all of the conditions affecting performance. It might be assumed that the development of four years should result in increased economy. This is not necessarily true, particularly with the smaller units, since the requirements of the service may necessitate mechanical changes whose desirability outweigh the relative importance of an inconsiderable increase in steam economy.

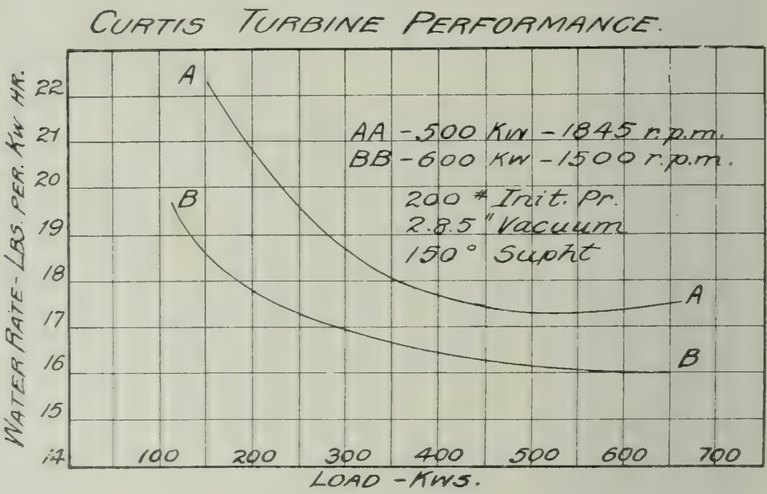


Fig. 13.

In Fig. 14 is presented the load curves of four Curtis turbines of 1,000, 2,250, 5,000 and 8,000 kws. rated normal capacity. In this instance the conditions of operation are not reduced to a common basis, but appear as actually observed. An inspection of the values given will indicate that no considerable change would result if a reduction had been made as in Fig. 13. The curve in Fig. 15 was constructed from Fig. 14, using the steam economy for the points of normal loading and all reduced to a common basis, namely, 185 pounds (gage) initial pressure, 28.5 inches vacuum, (30 inches Bar.) and 150 deg. Fahr. superheat. This curve illustrates the well-known fact that the ratio of the energy losses to normal capacity decreases with the increasing size of units, just as the same ratio varies with the load on a given unit.

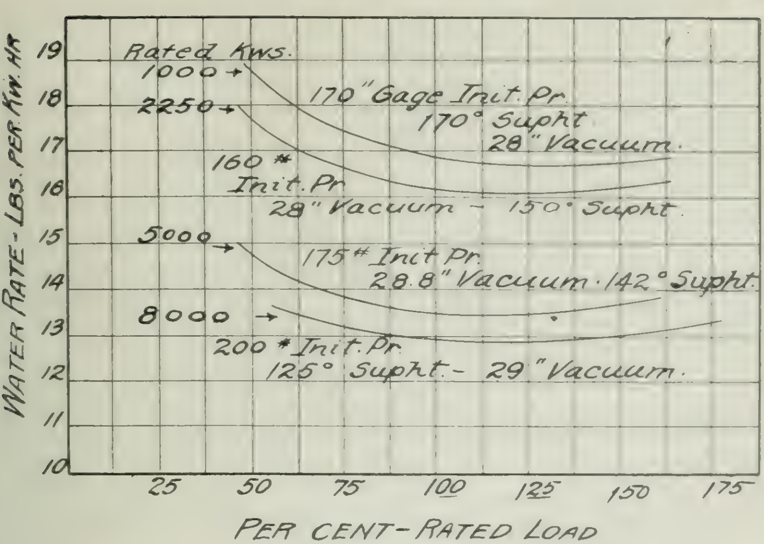


Fig. 14.

Corrections on these curves were based upon the following values, derived from actual tests, when all the conditions of operation, except those under trial, were maintained as nearly constant as precticable:

1 inch vacuum, between 26 inches and 30 inches = 5% effect upon water rate.

14 deg. Fahr. superheat = 1% effect upon water rate.

10 lbs. boiler pressure between 150 and 185 lbs. = 0.5% effect upon water rate.

Difference between 185 and 200 lbs. boiler pressure = neglible.

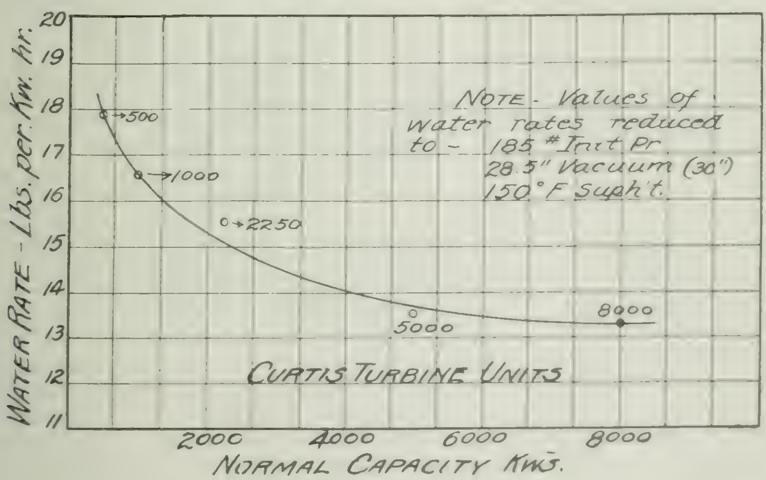


Fig. 15.

In the *Electrical World*, of October 12, 1907, the following corrections for departure from contract conditions during a test of a 7,500 kw. Westinghouse-Parsons turbine in the plant of the New York Edison Company, are recorded:

Pressure—2½ pounds high=corrections, 0.25% in water rate.

Vacuum, 0.69 in. low=correction, 1.84% in water rate.

Superheat, 4.25 deg. low=correction, 0.29% in water rate.

It will be noticed that the influence of the variation in steam pressure is apparently much greater with the Parsons type of machine and the influence of variations in vacua much less, than in the performance of the Curtis type. There is practically no difierence in the allowance made for superheat. It appears upon careful consideration that the turbine which governs by virtual throttling, would not be improved to any considerable degree by increases in pressure. Furthermore, the influence of vacua might be expected to be much greater than stated, concluding from experience with other machines.

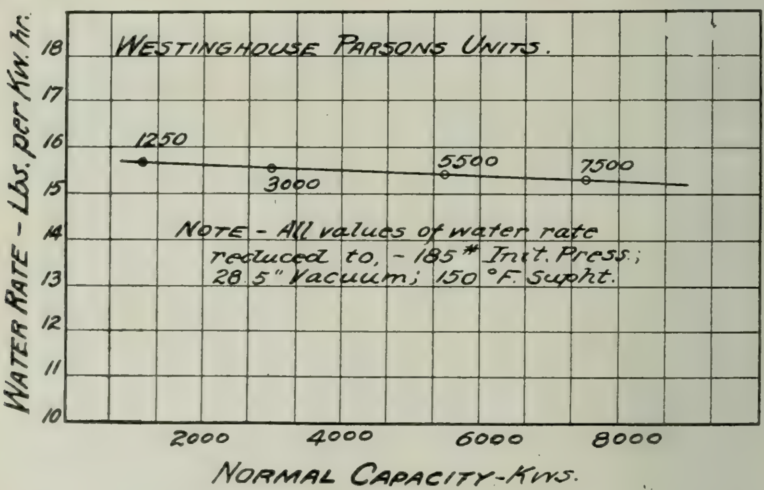


Fig. 16.

In Fig. 16 is presented the relation of water rate of various Westinghouse-Parsons turbine units, plotted upon the same basis as the curve in Fig. 15. The actual load curves from which this curve is obtained appear in Fig. 11. A marked contrast between Fig. 15 and Fig. 16 is immediately noted; a difference in water rate of 3½ lbs. existing between the 1,000 and the 8,000 kw. units of the Curtis pattern, and but 0.5 lb. difference over the same range of capacities in the Westinghouse-Parsons machines. This may be understood after a consideration of the constructive features of the two patterns of turbines. In the Westinghouse-Parsons pattern, the larger units are but magnified copies, if you please, of the smaller sizes, and thus

the energy losses bear the same relation to the capacity in any sized unit. On the other hand, the smaller Curtis turbine units are constructively quite different from the larger machines, and the ratio of energy losses to capacity is greater in the smaller sizes.

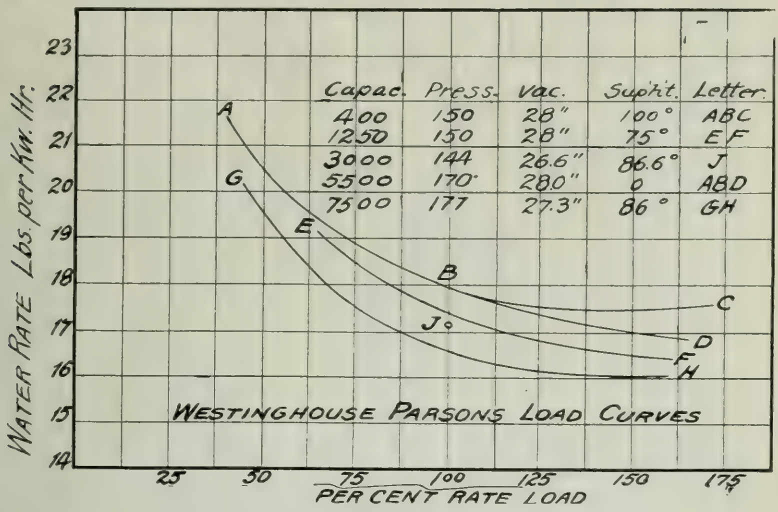


Fig. 17.

As mentioned above, Fig. 17, presents the steam economy of Westinghouse-Parsons units of various rated capacities, under the actual operating conditions. It is significant that the curve of water rate of the 400 kw. unit coincides with the curve of the 5,500 kw. machine up to their normal capacities. Both machines were operating under similar initial and final pressures, but the small unit was supplied with steam superheated 100 deg., whereas the initial steam for the large machine was saturated.

It is exceedingly important, as suggested above, that accurate means be secured for reducing the performance to a common basis for purposes of comparison, whether various types and sizes of units are involved, or the agreement of actual performance with guarantees in contracts is in question. For these purposes "performance curves" should always be determined which will present the variation in economy due to changing conditions of vacua, superheat, pressure, etc. Typical "Performance Curves" are shown in Fig. 18. Most significant of these curves and most worthy of special mention is the "Initial Pressure" curve, which demonstrates the futility, from the standpoint of economy, of increasing the initial pressure much above 140 lbs. gage. Up to this point the inclination of the curve is quite marked, and the advantage of increasing pressures as a means of reducing water rates very apparent. Beyond this point, the curve tends to become more nearly parallel to the pres-

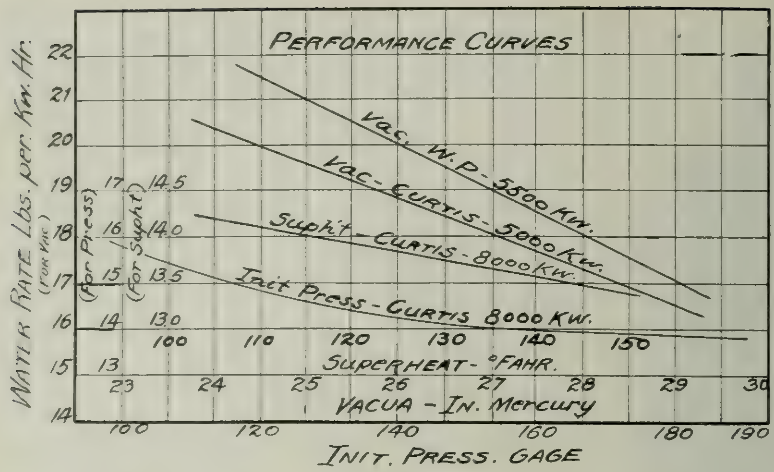


Fig. 18.

sure co-ordinate, indicating an advantage and that a somewhat questionable one. only in gaining capacity. This deduction is in accord with numerous investigations recently conducted, which have resulted in a diminishing of enthusiasm for high initial steam pressures. Some time ago, Professor W. F. M. Goss, Dean of the Engineering College at the University of Illinois, at that time occupying a similar position at Purdue University, presented a paper, which has been widely distributed, based upon investigations of the influence of increasing boiler pressures upon the performance of steam locomotives. The results presented were in direct accord with the preceding discussion. It will be of interest to mention that the government engineers in charge of the steaming tests of the U. S. Geological Survey have also advanced the proposition that lower steam pressures and high degrees of superheat will be found desirable and economical in the operation of steam prime movers. Curves of the same form as the one under discussion were secured in the Mechanical Engineering Laboratory at the University of Illinois from tests of a small turbine unit, of velocity or impulse type.

For some reasons it would be desirable to present performance and load curves for many other turbines that are now playing an important part in the design and operation of power plants. Numerous comparisons, however, have indicated that the curves here presented for the Curtis and Westinghouse-Parsons machines, representing, as they do, the two chief types of turbines, are characteristic both in form and in the absolute values given, of all steam turbines of their respective types.

Before passing from the consideration of steam economy, it will be well to consider examples of the numerous smaller machines that are attracting attention. Among the turbines of this class that have appeared quite recently are the Kerr, Fig. 19, the product of the

Kerr Steam Turbine Company of Wellsville, New York; the Sturtevant, Fig. 20, recently perfected, and now being vigorously supported by the B. F. Sturtevant Company, and the Terry, Fig. 21, built by the Terry Steam Turbine Company of Hartford, Connecticut. These small machines are all of the multi-stage impulse type, the Kerr applying the principle of the Pelton wheel and all of the other mentioned being modifications of the Riedler-Stumpf pattern heretofore discussed.

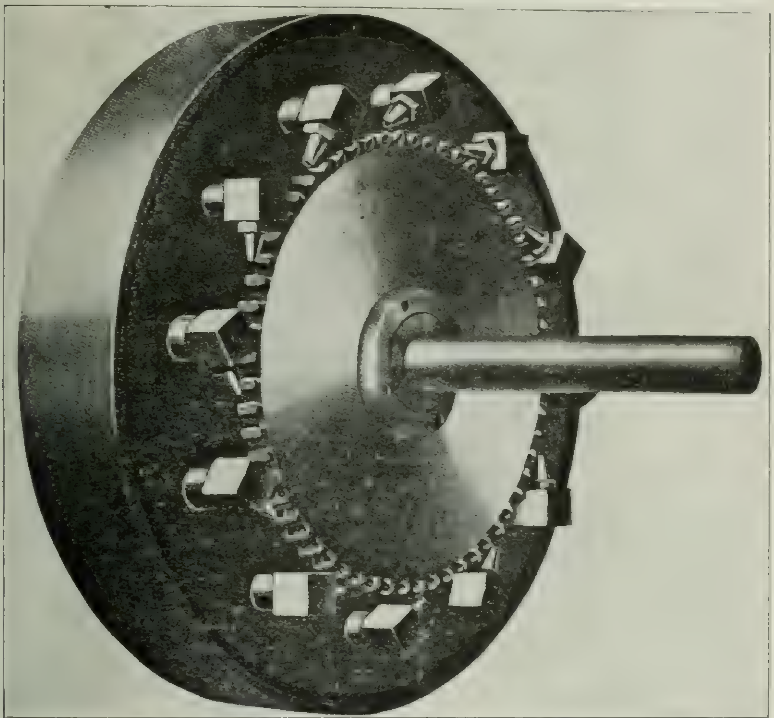


Fig. 19.

These small machines are designed for relatively small capacities of from 15 to 200 b. h. p., and usually for some special application such as driving D. C. electric generators, blowers, centrifugal pumps, etc., and where close regulation is desirable at comparatively high speeds. In general, they are designed to operate non-condensing, with saturated steam, and under such conditions give practically the same steam economy as a well designed high speed reciprocating engine of similar capacity. The accompanying curves, Fig. 22, show the close agreement of the steam economy of a high speed simple reciprocating engine, Curve AB, and a six stage Kerr Turbine, Curve CD, each rated at 60 b.h.p., and operating with an initial

steam pressure of 150 lbs. gage, 150 deg. Fahr, superheat, and exhausting to the atmosphere. Curve EF represents the steam economy of the same turbine, using saturated steam. It will be ob-

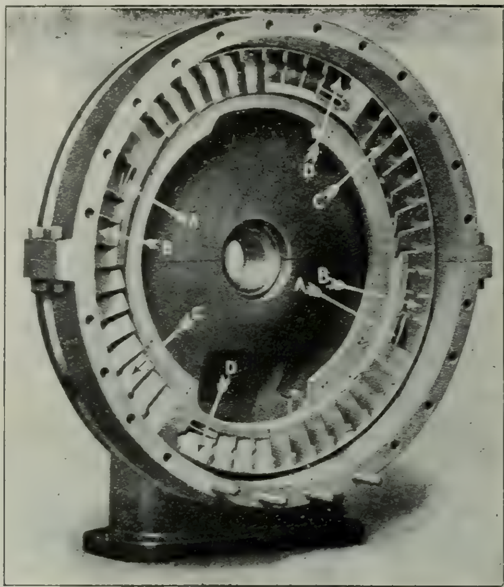


Fig 20.

served that the superiority of the turbine is quite apparent at low loads, due, no doubt, to the reduction of the windage loss occasioned by the decrease in density of the steam at lower stage pressures, a fact that is characteristic of large as well as small units. In this connection it will be interesting to note the graphical representation in Fig. 23, of the relation between Volume, Temperature and Pressures below atmosphere. The rapid increase in specific volume from 4 inches to ¼ inch mercury, absolute pressure, is closely related to the increase in turbine economy, noted in Fig. 10.

LOW PRESSURE TURBINES.

A number of plants have been installed more or less recently that have employed low pressure turbines as prime movers, which are operating on the exhaust steam from reciprocating engines in the same station. By this means great economy is effected in the use of the steam, and a saving of practically 65% may be effected by the use of a high-vacua condensing equipment. Practically all of the builders of turbines of large capacity have developed a low pressure turbine and these are playing a prominent part in the design of power plant extensions.

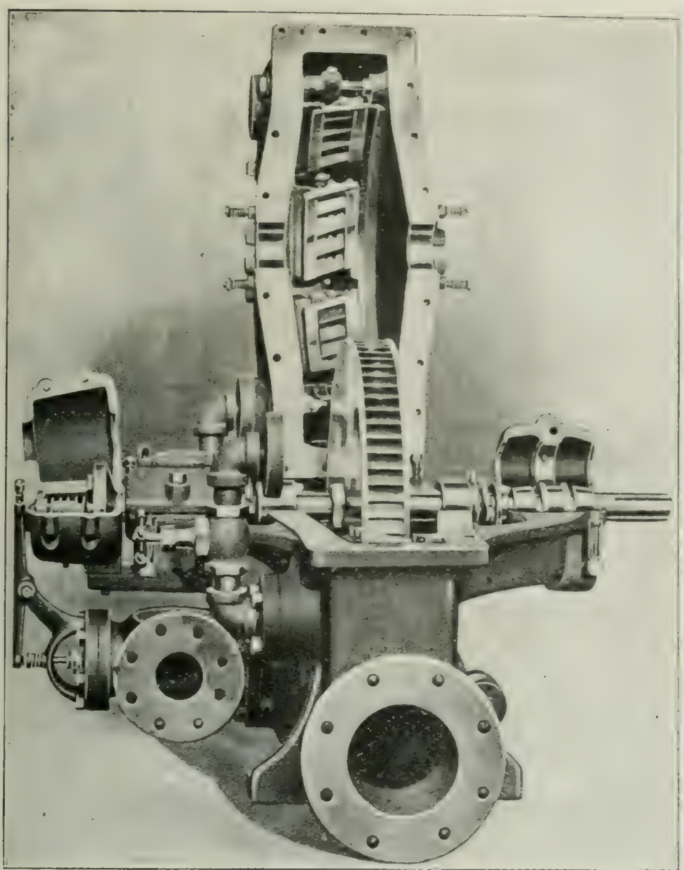


Fig. 21.

In many stations where reciprocating engines are installed they are operating non-condensing on account of the lack of an easily available water supply, and the very considerable expense involved in the installation of cooling towers. In such plants, low pressure turbines may be installed, which, operating between atmospheric initial pressure and 28 inches vacuum, will in many cases practically double the normal capacity of the plant. This, it is apparent, would justify the installation of cooling towers and the most efficient condensing apparatus, and the result would be attained without additional fuel or attendance charges. These turbines may be used to advantage with engines in intermittent service, such as rolling mill engines, where the steam supply is controlled by regenerating apparatus.

Mr. Lionce Battu very ably discussed the principles involved in this problem, in his paper before this society in September, 1904. One of the prominent installations of low pressure turbines been made indicate a water rate well within the guarantee.*

It may be of interest to know that the General Electric Company is now prepared to contract for the installation of Low Pressure Turbine Alternators of capacities (maximum continuous) ranging from 300 to 7000 kilowatts in machines for 60 cycle current with standard voltages; and of capacities from 1200 to 7000 kilowatts in machines for 25 cycle current and standard voltages. Low Pressure Turbine Units for Direct Current are built in sizes from 300 to 2000 kilowatts. The guarantees of steam economy is based upon initial steam of one pound gage pressure, exhausting into a vacuum of 28 inches.

Tests made in the shops of the Westinghouse Co. upon a 1250 kw. low pressure unit have resulted in a water rate of 30 lbs. per b.h.p.hr., this being the equivalent of approximately 38 lbs. per kw.hr.†

HEAT EFFICIENCIES.

The Willans Robinson Company of England, the builders of a popular and efficient type of reciprocating engine, have been experi-

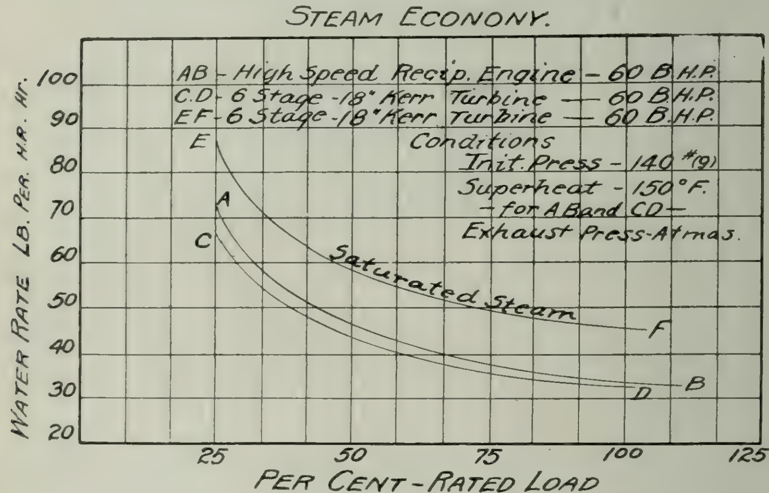


Fig. 22.

menting for some years upon improvements in the Parsons type of turbine. Results have been secured that are very satisfactory to

*French's Steam Turbines.
†J. R. Bibbins, Electrical Journal.

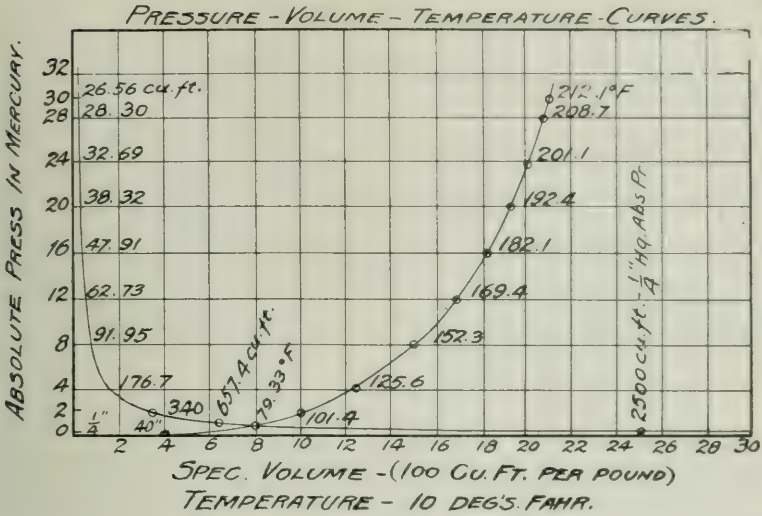


Fig. 23

the builders, and they are now doing a large turbine business. A contract recently entered into by this company for the construction and erection of a 3,000 kw. unit contained a performance guarantee clause, stipulating a water rate of 12.9 lbs. per kw.-hr. No data was presented with reference to the conditions of operation, but by reference to the curves of Fig. 8, it will be seen that this is equal to the best performance of the 8,000 kw. Curtis turbine.

Now, just what does it mean for a turbine to develop a kilowatt at the switchboard on a steam consumption of 12.9 lbs. per hr.? This is the equivalent of 9.54 lbs. per e.h.p. or with a generator efficiency of 96% it is the equivalent of 9.17 lbs. of steam per b.h.p.hr., further, assuming a mechanical efficiency of 94 per cent for the prime mover, it is the equivalent of 8.62 lbs. per i.h.p.hr., certainly a commendable performance. According to the British Standard as recommended in the report of the committee of the American Society of Mechanical Engineers on Standard Code for Steam Engine Tests, this performance gives a thermal efficiency of 21.4%, closely approaching the best performance of internal combustion engines. The "potential efficiency" of heat engines presents a much more satisfactory basis of comparison than "thermal efficiency" just discussed. This efficiency is defined as the ratio of the ideal to the actual heat change per unit of power. Assuming an absolute pressure of 190 pounds, 150 deg. F. superheat and a vacuum, referred to 30 in. barometer, of 29 in., the above water rate is the equivalent of a potential efficiency of 67.7% based upon energy delivered to the switch board and 75% based upon indicated horse power deduced as explained above. In comparison

it is interesting to note that the official trial of a 1000 i.h.p. double-acting, twin-compound Schmidt engine, operating on 155 lbs. initial steam pressure, 25.4 in. vacuum and 330 deg. Fah., superheat, gave a potential efficiency of 83.3%. This represents the best modern practices.

Thus it will be seen that we are fast approaching the limit of economy in the prime mover itself, and future developments must be looked for in the steam generator. Greater economy must be secured in the performance of the boilers. It is significant that practically the same rated boiler capacity was installed for the first 5,000 kw. unit in the Fisk Street Station of the Commonwealth Edison Company of Chicago, as six years later, was installed to operate the 9,000 kw. units. This points to developments in boiler practice as well as to remarkable advances in the large turbo units.

BOILER ECONOMY.

In most plants, the steam driven auxiliaries do not furnish enough exhaust steam to heat the feed water above 120 deg. Fah. The possibility of increasing economy by using *hot* feed water has been taken advantage of in some cases by the installation of economizers, though their ultimate practicability still remains a much discussed question. Other engineers have taken steam from the second or third stage of the turbines to increase the feed water temperature and this without suffering a deleterious effect in economy.

In a recent article before the American Institute of Electrical Engineers, Mr. J. T. Findlay presented a very interesting discussion of experiments with double stoker boilers in the power plant of the Interborough Rapid Transit Company of New York City, made under the general supervision of Mr. H. G. Stott, superintendent of motive power of the Interborough Company. These boilers were 500 h.p. units set with two Roney stokers, one as in the standard setting and the other at the rear at a somewhat lower level. The horizontal baffling was so arranged that the gases from both stokers intermixed and traversed the same passes over the heating surface. This increase in volume of gases, with the resultant higher velocity, effected an increase in capacity of 80% with no appreciable difference in overall efficiency.

This suggests what is very much discussed, namely, the possibility of securing a greater amount of work from our boilers. It leads to the prediction that we are rapidly approaching the point when we will be able to rate water tube boilers on a basis of five square feet of heating surface, per h.p. instead of ten, as now used. Experiments such as are now being made, of which the one cited is a good example, foreshadow the design and operation of larger boiler units, the reconsideration of generally accepted theories regarding heat transmission through boiler heating surface, and the re-design of boiler settings that have been standard for years. There must be a

constant striving for better evaporative performance;—for a decrease in the radiation and unaccounted for losses in boiler practice, if this factor in power plant development is to keep pace with the modern prime movers.

RATING OF STEAM TURBINES.

An inspection of the curves of Fig. 14 and Fig. 17 suggests a very significant fact pertaining to the rating of steam turbines. The maximum steam economy is obtained at loads varying from 115 to 130% of the rated capacity of the units, and no considerable increase in water rate occurs at 150% of the normal rating. This is in direct contrast to the conditions which obtain in reciprocating engine practice, where increasing the load above the normal rating or point of maximum economy, brings about a marked increase in the water rate. The reciprocating units are designed to sustain a certain overload for a period of time, usually 50% for two hours, but it is obvious that this maximum capacity should not form the basis for normal rating. In the light of these facts, a change is being effected in the system of rating turbines, and it will not be long until such rating will be based upon the continuous maximum operating capacity instead of upon a normal load basis of the turbines, and generators will be installed capable of such continuous operation. It will be seen that this will not present a radical departure from the practice which now obtains with reference to some prime movers, such as gas engines or water turbines, where the best porformance occurs at points of maximum capacity, and where guarantees of performance seldom contemplate any considerable overload capacity.

The General Electric Co. are taking a prominent part in effecting the changes in the rating system just discussed. The guarantees of this company will contemplate continuous operation at maximum capacity. It seems reasonable to suppose that this method of rating will soon govern the practice of all builders of turbines, particularly of units of large capacity.

VENTILITION OF GENERATORS.

The operation of turbo-alternators at their maximum capacity for periods of considerable length has caused some little concern regarding the ventilation of the generators, on account of the unusual increase in temperature of the windings, in a number of instances. In the vertical machines where the generator is placed upon a low stool directly above the turbine and separated from it by a short distance, various systems have been used with varying degrees of success until now a special duct is sometimes provided for the introduction of cool air, the flow being superinduced by the draft of the rotating element. It can be seen that the problem presented is more complex in this instance than in the case of the horizontal machine. In the latter type of turbine, the closed type of generator, Fig. 24,

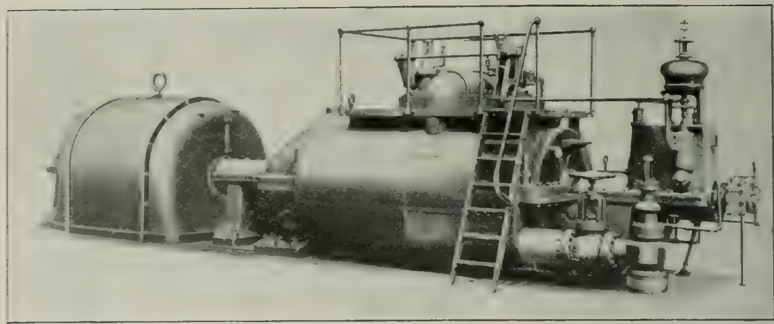


Fig. 24.

has become quite popular. This form of construction permits the application of a very effectual closed forced or induced draft system with the blower on the generator. In some cases this is supplemented by an independently driven blower to reduce the heating effect during periods when unavoidably heavy overloads occur. This careful attention to generator ventilation insures greater safety and makes possible the attainment of an overload margin hitherto quite impracticable and unsafe.

CONCLUSION.

A number of matters pertaining to recent steam turbine development have been discussed. There are many others that might be profitably considered at this time, such as improvements and inventions pertaining to system of governing, methods adopted for securing blades to the stationary and rotary elements to prevent dangerous stripping, new devices for balancing end thrust in horizontal machines, the design and operation of large condensing units, etc., etc. All of these are of importance and constitute the distinguishing features in particular machines, but lack of space prevents a discussion of them at this time.

In conclusion it should not be said or inferred that the steam turbine is supplanting the steam engine in the broad field of the latter's usefulness, nor that the days of the "old reliable" are numbered. Certain it is, however, that for electric generation for all purposes, particularly in large units, the steam turbine of the past decade has proven its superiority.

The importance of the subject in hand should impress every engineer and it is urged that a continuous effort be made by our society to keep pace with the rapid progress of the steam turbine as a prime mover. It is hoped that the discussion of this paper will develop interesting and valuable information for all.

STEAM TURBINE DEVELOPMENT.

Chronological Table.

120 B. C.	First Reaction Turbine, Aeolpile; Hero of Alexandria.
1629 A. D.	First Impulse Turbine. Grovannia Branca of Rome.
1629	First Attempt to Utilize Steam Turbine at Moderate Speeds. Real and Pichon, France.
1831	First United States' Patent. 10 H. P. Reaction Turbine. Wm. Avery, Buffalo, N. Y.
1838	Experiments with Expanding Nozzles in "Avery" Turbine. Leroy.
1842	Compound Principle Applied. Attempt to Design Reversing Turbine. Pilbrow.
1848	Compound Reaction Turbine, the Forerunner of the Parsons Type. First to Properly Consider the Effect of Increasing Volumes with Decreasing Pressures. Wilson.
1853	Speed Reduction by Gears. Cut Off Ring for Governing. Delonchant.
1858	Compound Impulse Turbines, Suggesting the Modern Curtis Machine. John and Ezra Hartman.
1863	Return Pipes and Double Set of Blades to Cause Double Action of Steam on the Same Wheel, Hoehl, Brakell and Gunther.
1877	Compound Impulse Turbine Employing Gradually Increasing Steam Areas. Forerunner of Hamilton-Holzwarth Machine. Moorhouse.
1879	Compound Radial Flow Turbine. Cutler.
1881	Compound Impulse Turbine with One Wheel. Semi-Circular Buckets. Imray.
1883	Speed Reduction by Friction Gearing in Turbine of "Avery" Principle. This was the First Patent of the Famous De Laval.
1884	Radial Inward Flow Turbine. Speed Reduction by Spur Gears and Pinion. Babbitt.
1885	Balanced End Thrust by Dividing Machine into Two Separate Sections. Hon. C. A. Parsons.
1888	Pressure Stage Feature Invented. Parsons.
1893	Radial Outward Flow Type. A Popular Machine of the Early Day. Dow.
1894	Expanding Nozzle Patented. De Laval.
1894	Patent Covering Use of Expanding Nozzles with Compound Impulse Turbines. Precedes Curtis Patents by Two Years. Maison Breguet.
1894	Beginning of Pelton Wheel Type of Steam Turbines. McElroy.
1894	Single Wheel with Pelton Buckets, Employing Special Reversing Mechanism. Rateau.
1895	Design of "puff" Governor for Parsons Type of Construction. Parsons.
1895	Applies Expanding Nozzles to Compound Impulse Turbine. Another Forerunner of the Curtis Machine. Sebastian Ferranti.
1896	Group of Patents Secured by C. G. Curtis, now Controlled by General Electric Company. Various Points Covering the Application of Expanding Nozzles to Multi-Stage Impulse Turbines. Special Curtis Governor.
1897	Effort to Mix Water with Steam to Reduce Velocity. Fault Lies in Reduced Kinetic Energy. Bollman.

1898	Special Modification of Pelton Wheel Buckets. Nickel Steel Square Section Expanding Nozzles. Nickel Steel Wheel Discs. Stumpf, Berlin.
1900	Radial Arms Machined in the Shape of Pelton Buckets for Considerable Distance from Circumference. Zoelly.
1903	Modified Form of Zoelly Turbine. Cup Shaped Buckets. Wheel and Speed Reducing Gears Rotate in Steam Chamber to Reduce Noise. Increase Durability and abolish Packing Glands. Richards.
1904	Cup Shaped Pelton Wheel Buckets. Throttling Governor. Designed to Run Non-Condensing with Saturated Steam. Kerr.
1905	Warren Steam Turbine. Composite Type Providing Expansion only in fixed Blades. Drum similar to Parsons Type. 100 to 3,000 Kw. Units. Warren Electric Manufacturing Company. Mr. E. C. Crocker.
1905	Hamilton Holzwarth. Modifications of Riedler-Stumpf. Composite Type. Throttling Governor with One Main Valve. High and Low Pressure Sections for Large Units.

DISCUSSION.

President Loweth: What is the relative durability of the steam turbine as compared with the reciprocating engine? Has the steam turbine been in service long enough to determine that?

Prof. Thorpe: I cannot answer that question positively, Mr. President. Turbines have been installed for years, it is true, and yet the changes have been so marked throughout recent years it would be difficult to base any estimate on anything except maintenance charges and data of that sort, which are not always available. The simplicity and construction would have some bearing upon that, and I see no reason why the steam turbine should not be even more durable than the reciprocating engine.

Mr. W. L. Abbott, M.W.S.E.: I think this Society is fortunate in having this matter presented by one who not only is thoroughly familiar with the theory of the turbine, as a professor of Mechanical Engineering, but also is familiar with it as a practical working engineer.

At the beginning of the paper we were shown what the earliest steam prime movers were—steam turbines—and for several centuries the entire development of steam power was in that line, and had it not been for the impetus given to reciprocating engines by the work of Watt, and others of his time, the turbine would very likely have been commercially developed a century ago, and would have been the real (steam) prime mover, but on account of the work done by those engineers, the reciprocating engine was developed to a higher degree than the steam turbine, and therefore held the field. Work on steam turbines was, however, continued by various inventors, and I think a careful study of the history of the subject would reveal the fact that at any time during the past 125 years the steam turbine has not been more than two decades behind the reciprocating engine, in its development. In other words, had the de-

velopment of the reciprocating engine been delayed, say, twenty years at any time, or had there been such an impetus to the steam turbine as we had given to the reciprocating engine, the turbine would have been the commercial prime mover long ago.

The speaker shows a diagram containing three curves, representing the improvement in the economy of the Curtis turbine within a period of, say, five years. The water rate on the first was about 24 lbs.; the water rate on the last one is but a little more than half that.

In the latter part of this paper some figures are given, showing that the turbine now is developed to within 25 per cent. of the ultimate possibility. That is, we now realize within 25 per cent. of the highest economy which will ever be possible with the steam turbine or any other steam motor. When we consider that within the past five years, we may say, the water rate has been cut in two and consider what little margin remains to work on, we see that the steam turbine, as far as efficiency is concerned, is very near the end of its road. There are possibilities remaining yet, of course for improvement in its general design, greater reliability perhaps, or cheaper construction, etc. There is also a possibility of improving boiler economy by perhaps one-third, but when we approach the not distant limit of economy of the boiler and of the turbine we shall be obliged, as the speaker intimated, to turn to some other prime mover to obtain still higher economies.

The development of water power is now demanding the attention of engineers and capitalists, but to me it seems that those who are putting their money in these ventures do not fully realize the changed conditions brought about by the development of the steam turbine. A steam power house can now be built at a cost far below the development cost of most any water power, and the fixed charges on the steam turbine plant, if located near the place where its power is to be used, will be far below that of a water power with a long transmission line. The power of Niagara Falls, or any other great waterfall, is, of course, a potential source of wealth, but its value I consider has been greatly diminished relatively of recent years by the development of the steam turbine and the general development of large power houses, which permit the generation of power from coal with a lower initial investment, and with very little higher operating costs.

President Loweth: The steam turbine seems peculiarly adapted for the generation of electrical energy and for marine purposes; is it being used to any great extent for other than these purposes?

Professor Thorpe: There are a number of special applications of the steam turbine, and perhaps the most prominent one is that in connection with centrifugal pumping machinery. The recent development in design and operation of centrifugal pumps presents a promising field for the steam turbine. Most of the turbines of smaller capacity have also been used in blower work.

Prof. A. W. Moseley, M.W.S.E.: I always rather assume that the over load capacity is limited largely by the electrical rather than the steam part of the unit, particularly with turbo-generators. I would ask if that is not true, or whether it is more a matter of electrical design to make the generator of sufficient capacity?

Prof. Thorpe: I have in mind instances where the opposite conditions have been obtained in machines of very similar construction. I believe that the generators will always be designed, as far as possible, to take care of the overload capacity of the turbine. For example, if the turbine's maximum capacity is 14,000 k.w., the guaranteed maximum operating capacity of the generator will also be 14,000 k.w.

Mr. C. G. Y. King: I was recently in a small town where I saw a turbine that had been opened up for investigation and some slight repairs, and in which there was a heavy deposit of mud. This turbine was operated by what was considered to be pure steam. The circulating water was taken from the river and was passed, through the surface condensers; the steam was supplied by one or two boilers through a superheater. What I would ask is if anyone knows of a similar case, and what the condition of the superheater was; how much mud there was in it, and what effect the mud had on the buckets of the turbine.

Mr. A. Bement, M.W.S.E.: In answer to Mr. King's inquiry, I will say that it is probable that mud was carried into the superheater by water which went out of the boiler with the steam, or in other words, by a condition of priming. This is entirely reasonable, as we know that it occurs where superheaters are not employed, due to improper design in boiler drums which allow water to be carried with the steam, and such water will be accompanied by mud that is present as a scum on the surface.

Prof. Thorpe: It is comparatively easy to tell what would happen to the turbine if it were continually operated on steam and mud. Most of us have seen pictures of corrosion due to wet steam, and if there are any solid particles it would only aggravate that condition until the turbine would finally become of no use at all.

President Loweth: What is the relative cost per H.P. of large and small sizes of steam turbines as compared with reciprocating engines of approximately equal efficiency. Of course the answer to this question must necessarily be but a roughly approximate one.

Prof. Thorpe: In order to arrive at a satisfactory estimate on that particular subject, we ought to agree to take the prime mover and generator together as a direct-connected unit. Ordinarily we think of the medium size of reciprocating engine and generator as costing about $35.00 to $40.00 per k. w. In any event, with machines of similar capacity I believe the first cost of the turbine driven unit would be slightly less than for the reciprocating engine.

Mr. Wm. B. Jackson, M.W.S.E.: In his remarks, Mr. Abbott

spoke of the possibility of having come pretty well toward the limit of efficiency in the matter of steam turbines. In this, however, I am hardly willing to agree, because in the old days, when we were getting 88 per cent., we thought we were very nearly the limit and then ran that up 10 per cent. better. We also have the saving that is just as active and important in the question of cost which the President has just brought up, and there is no reason to suppose that at the present time we have even approached the limit of reduction in the cost and manufacture of the steam turbine generating unit. In that same regard it seems worth while to emphasize the fact that, although the efficiency element may be very different as regards the steam turbines and internal combustion engines, yet there again we have that element of cost, which is a very important factor as determining the value of machinery.

Prof. Thorpe: One instance of a large machine showed rather a decided inclination of the water rate curve away from the horizontal axis, as represented in the chart tonight. That is the condition—it is practically the same except not quite so aggravated as obtains in the reciprocating engine.

Mr. P. Junkersfeld, M.W.S.E.: Mr. Jackson called attention to the possibility of further reduction in cost of the steam turbine station. That reduction can be made in two ways. Of course there are some further possibilities in reduction of first cost of the unit and in increasing its efficiency. In neither of these elements, however, is the field very wide. The largest possibility is in reduction of cost of other elements that go to make up the station. It is the incidental saving, rather than the direct, that offers by far the greatest possibilities.

Prof. Thorpe states in his paper that a contract was recently entered into by the Willans-Robinson Co. of England, for the construction and erection of a 3,000 kw. unit which contained a performance guarantee clause, stipulating a water rate of 12.9 lbs. per kw. hr. Two years ago the standard guarantee of the A. E. G. Co., of Berlin, was 13.2 lbs. per kw. hr., so that, in the last two years they also have come to the top of the curve and have not made much further headway,—the guarantee being very little better than that of two years ago. It is with pride that we note that one of the turbines which has made particularly good headway, is of American invention, most of the other patents being controlled abroad.

Referring to the question in regard to the generator: There have been some new experiences within the last two years, largely due to the fact that the generator design for turbines was necessarily patterned after water-wheel practice. After the large turbines were run with generators, it was found that an entirely different condition existed. The large amount of energy given off in such a comparatively small mass meant that the maximum temperature would be reached in a short time—less than half an hour. The result has

been re-rating of the turbines and building the generator big enough so it can reach its maximum temperature in that space of time.

Mr. A. Bement, M.W.S.E.: Professor Thorpe's paper is of the very greatest value and to my mind the best contribution I have read on the subject of the turbine. Its development is very clearly outlined, enabling one to readily see that the machine has arrived at its present stage of growth by a natural process. To me, the most important feature of the paper as indicating the enormous improvement that has taken place, is the diagram, Fig. 12, the water rate curves therein speaking for themselves, and in a graphic manner demonstrating the advancement which has occurred within the last five years. When it is considered that the steam turbine as a commercial machine has an existence of but a few years, it is decidedly significant that such great improvement should be effected in so short a time, and this appears favorable to early realization of additional development.

This leads to the matter of desirable initial steam temperature or degree of superheat, and I would like to ask Professor Thorpe what degree of superheat he considers most beneficial, and if he has any reason for limiting it as long as it is not of sufficiently high temperature to cause damage to metal parts of the apparatus.

In reference to the tests by Dr. Goss with high pressure steam in locomotives, I do not think the reasonings would apply to turbine conditions, because if I understand rightly, the difficulties with the locomotive were those of lubrication, leakage through joints, etc., features which do not have an application in turbine practice. The experience of the United States Geological Survey probably has not been sufficient to establish an authoritative opinion relative to the matter of desirable steam pressure. This idea originated, I think, while Mr. Ray was in the employ of the Chicago Edison Co. At that time it was my observation to him, that the relatively greater economy of the steam turbine at low as compared to high pressures, suggested the feasibility of carrying less steam pressure to insure a lower temperature of the contents of the boiler, so that heat absorption would be more complete with consequent higher efficiency in steam generation, and the question was, whether this would be sufficient to overcome the loss in the turbine due to the reduced pressure, and this line of inquiry suggested the possibility of very high superheat in connection with it, but I am not aware that the Geological Survey has given the matter further consideration. It is a fact, however, that European experience (that of Schmidt, for example, who obtained very high efficiencies with reciprocating engines), was with steam at a high degree of superheat, but with prevailing types of boilers high superheat requires the superheater to be located close to the fire rather than near the chimney, so that the hot gases may act upon it after having passed over only a small portion of the boiler surface.

I think it unfortunate that as a general thing there has been so little discussion of the factors which influence efficiency with turbines. After all, when the matter is summed up, it would appear there are only three possible sources of loss, to-wit:—

a. Heat in the exhaust.

b. Radiation from the exterior of the machine,

c. Velocity in the exhaust,

and strictly speaking, I do not think that items 1, 2, 3, 4 and 5 given as losses on page 540 of the paper, should be so considered for the following reasons:—

Friction between steam and the metallic surfaces must result in the generation of heat. This heat is either returned to the steam flowing through the machine or else radiated away from the exterior of the casing, but inasmuch, however, as it cannot raise the temperature of the turbine casing from that due to normal condition, it could not contribute to the radiation loss, therefore the heat would find its way into the steam to be transferred into work, or else would escape with the exhaust. The same reasoning applies to friction due to eddy currents, likewise the resistance of the steam to rotation known as windage. The mechanical friction of journals, etc., which are located in the steam spaces, would contribute in a measure to heating of steam. The figure of 5 per cent, however, is so high that it raises the question whether the friction of the entire machine, generation included, is not charged against the turbine. At all events, for a study of the heat efficiency of the turbine, it would be desirable to eliminate the consideration of what is strictly mechanical friction occurring outside of the steam chambers of the machine. According to the foregoing, the improvement in the turbine must certainly have occurred through a reduction in the amount of heat carried away in the exhaust steam. The theory of the turbine demands that it be more efficient than a reciprocating engine, and if I am not mistaken, it was prophesied that such result would be obtaied, and early experience must have been more or less of a surprise. In view of the fact, however, that so great improvement has been accomplished in the last few years, would indicate that if still more energy of the steam can be transformed into work through perfection in mechanical design and construction, there will be a demand for a very high degree of superheat.

In steam engine practice the term leakage is quite a significant one. Somehow it has not been considered so important a matter with reference to the turbine, but I think that leakage, or in other words, a condition which allows steam to blow through the machine into the condenser without doing work, should have more recognition than it has thus far received.

Relative to the improvement in the first unit of 5000 kw. capacity and the later ones of 9000, I feel that the gain has been very largely

in the turbine rather than in the boilers, as the following tends to show:

Boiler, square feet	5200	5200
Superheater, square feet	960	960
Grate surface in square feet	75	90
Height of chimney, feet	200	250

which I think shows that the increase in capacity from the boilers is due to a larger grate and a higher chimney, or in other words, increased facilities for burning coal; while on the other hand, the comparison between the turbines is as follows:

Rated capacity, kw	5000	9000
Water rate per kw., pounds	23.85	12.94
Pounds of steam required per hour, per turbine	119,250	116,460
Ratio between steam quantities required	1.024	1.00

Thus it will be observed that the demand for steam by a 9000 kw. turbine is 2.4 per cent less than that required to develop 5000 kw. with the old machine, eight boilers, of course, being employed in both cases to supply one turbine.

The matter of ventilation of generators is one which interests me very much, and I am glad to see that Professor Thorpe has said something about it. In this connection I would like to ask him what the prospects are for closing up generators so that noise may be eliminated, and, effecting ventilation by other than natural means. To me the greatest objection to turbines is the noise made, which with the early example of the Westighouse-Parsons before a jacket was applied, was very serious and dangerous, as it was impossible to know through sense of hearing what was going on in the turbine room. I do not believe the matter has been taken up seriously with the realization of what the requirements demand. The magnitude of the problem may be apprehended if we assume a station of ten turbines each of 9000 kw. capacity, with a 98 per cent efficiency. This would mean a liberation of 6,141,600 heat units per hour equal to burning of 585 pounds of coal in the same length of time, sufficient to raise 5,174,136 cu. ft, of air per hour 5 degrees in temperature. The present tendency is, of course, toward a much larger and more expensive generator, having high efficiency and consequently wasting less energy in the form of heat, which simplifies the problem.

Prof. Thorpe: With respect to the two questions brought up by Mr. Bement, his inference is true that the tests recorded in the paper on superheat engines were made with a high degree of superheat—600 deg. Fah. It is characteristic of foreign practice to use those high degrees. The average in this country I think might be said to be 125 deg. Fah., or perhaps a little less. The possibility in the use of higher superheat is very promising, it seems to me, and I

believe most of us are looking forward to developments along that line. We were limited in the past by mechanical difficulties rather than a more or less complete understanding of the steam action itself.

With reference to the ventilation of generators, I feel hardly qualified to speak on that subject. I think Mr. Junkersfeld can present more valuable data on that subject than I can, owing to his intimate knowledge of electrical design and his relation to that practice. No doubt we are all familiar with the efforts being made by generator designers to lessen the noise and give better ventilation. In one of the pictures shown was a Westinghouse unit completely inclosed.

This feature is embodied in the late designs of turbo-generators by all of the prominent builders. It makes possible the use of mechanical ventilating systems, and reduces the noise to a minimum.

Mr. Junkersfeld: With reference to the matter of ventilation and lessening the noise of generators, this is something that all the maufacturers are still working on. It is easy enough to close a generator, but not so easy to keep it closed and get results. I think that after another two years have gone by, some of the problems that are now puzzling us will be solved. There are a good many installations under way which will be quite different from anything thus far in service, and we shall have to wait a little time before we can judge of their effectiveness.

President Loweth: Our Past President, Mr. Abbott, suggests that perhaps there are some engineers who have not kept pace with the improvements being made in steam turbines, and the speaker, speaking for himself, knows this to be true. In this age of rapid evolution in engineering matters, there is a great deal more going on than one mind can well keep in touch with. Great credit is due to those engineers who have so rapidly brought the steam turbine to such a high degree of efficiency, and especially to those who have had the courage of their convictions, both to buy and to sell such large units as have been lately successfully installed, and it is gratifying that their success has been so marked.

Mr. C. V. Kerr (by letter): I am glad to see Prof. Thorpe take the stand he does on comparing the performance of heat engines on the potential efficiency. We have for a long time rated water wheels on the ratio of work developed to the potential energy of the water fall. As steam expands adiabatically a certain amount of heat is made available for conversion into work and there is no chance whatever for the engine to develop more than this theoretical quantity. In the gas engine also there is an available heat represented by the fuel value above the normal level of atmospheric pressure and 32 degrees F. This potential efficiency basis, therefore, gives a just comparison of the performance of different classes of prime movers under the conditions in which they are compelled to operate. On

this basis steam turbines and steam engines have developed from 70 to 80% by record tests of the theoretical amount of power. Water wheels have developed 80 to 85%. The gas engine, however, developing a b.h.p. on 12 cu. ft. of natural gas with a heating power of 900 B.t.u. per cu. ft. has a potential efficiency of only 23.5%. It is, of course, true that the actual fuel consumption of the gas engine per b.h.p. is less than that of the best performance of the steam turbine or steam engine at present. As compared with the steam engine, however, the gas engine shows a far lower potential efficiency. The steam boiler will put into the steam from 70 to 75% of the fuel value of the coal burned. The combined efficiency of the best boilers and the best steam turbines will be close to 50% efficiency on the basis of available heat due to expansion of the steam.

There is a great field for the steam turbine driven auxiliaries in power plants. As stated, in most plants the auxiliaries do not furnish enough exhaust steam to fully heat the feed water. The exhaust steam from the steam turbine is entirely free from oil so that no trouble or danger comes from this source to the boilers. With the installation of turbine driven boiler feed pumps, circulating pumps, hot well pumps, exciters, blowers for forced draft and the like, the demand for exhaust steam to heat the feed water will be met with a supply of exhaust as clean as when it comes from the boilers. If my information is correct trouble has come in economizer installations due to sweating of the tubes when cold feed water is passed thru them. If the exhaust steam from the auxiliaries is first used to heat the feed water and it is afterwards passed thru the economizer tubes such trouble with sweating will be largely avoided and the further use of chimney gases will lead to the highest possible efficiency of the plant.

In the case of the small steam turbine used for driving blowers, centrifugal pumps, generators and other high speed machinery, it is almost absurd to take any other rating than that based on the continuous maximum operating capacity. If a blower requires 30 h.p. what is the use of putting a turbine on it that is rated at 25 h.p. and giving it an artificial 20% overload capacity to meet the demands of the blower? The same thing is true of the centrifugal pump, as well as of driving generators. It is the custom of my Company to put into the turbine the maximum h.p. that is to be required of it under operating conditions no matter what the driven machine may be and to rate the turbine accordingly. I believe this is the right way to meet the question of rating and that this practice will finally prevail.

Prof. G. A. Goodenough (by letter): In the question brought up by Mr. A. Bement regarding the losses in the steam turbine, we must take issue with Mr. Bement's statement that Items 1, 2, 3, 4 and 5 of page 549, should not be considered as losses. Take the case

of Item 3, Resistance to the Rotation of Moving Parts in Atmosphere of Steam, or Windage. Here work is converted into heat, and as Mr. Bement states, the heat is returned to the steam in subsequent stages. To be sure, there is no loss of energy; that is, our law of conservation of energy is not violated. There is, however, a loss of availability; that is, the heat that has been produced by the work can in no way in the subsequent stages be made to give back the work that was expended in generating it. In fact, it can be made to give back only a very small fraction of that work.

For example, suppose that in a given stage 10,000 foot-pounds of work are expended in windage. This means that the equivalent of 10,000 foot-pounds is produced as heat at some definite temperature. Now if the thermodynamic efficiency of the turbine reaches the high value of 20%, then not more than 20% of the 10,000 foot-pounds can be recovered as work; the remaining 80% must inevitably be lost.

The same statements may be made of the other items, Friction between the Steam and Blades, Friction Due to Eddy Currents, etc. These losses are good examples of the real meaning of the second law of thermo-dynamics, or in a broad sense, the law of degradation of energy. All of these frictional processes are irreversible and give rise to a certain loss of availability.

CLOSURE.

Prof. Thorpe: In closing the discussion, a few points mentioned heretofore may be considered very briefly.

First, in reference to cost of turbines it may be said that the great factor in economy is noted in decreased floor space required and in the great lessening of foundations. The vertical turbines occupy about two-fifths and horizontal turbines about three-fifths of the space of reciprocating engines, and are so well balanced that units of large capacity have been placed upon the second floor of power plant buildings. Where real estate values are high, this feature is of significant importance when referred to the plant initial cost.

Second, in reference to the matter of high steam pressures discussed by Mr. Bement, it seems to the writer that Dr. Goss' work at Purdue resulted in most conclusive evidence that the value of high steam pressures has been overestimated. The fact that this evidence was collected in locomotive service need not present a questionable condition. That the locomotive, though operated under the most trying conditions, is a very economical power plant is not to be denied.

In further reference to Mr. Bement's discussion, his remarks on energy losses in the turbine are very interesting and timely, though if a general comprehensive classification of these losses were attempted, it might well consist of two items: first, Thermal Losses; and second, Mechanical Losses. In the discussion of this subject, the writer attempted only to present the various conditions affecting the total energy loss. Professor Goodenough has explained very clearly

that there must be an ultimate loss due to the conditions named, based on the theory of "The Degradation of Energy," which affects the operation of all prime movers.

Third, in reference to Mr. Kerr's discussion of the coal rate of the turbine as compared with the Gas Engine which boasts of its brake horse power per pound of coal, it may be said that if the same grade of coal were used under the boilers, the steam turbine, too, would develop an electrical horse power on one pound of coal.

In closing, the author wishes to thank those who have contributed to the discussion, and to acknowledge the very considerable courtesy of Mr. French, for permission to present some material from his splendid book on "Steam Turbines," and of the various turbine builders whose co-operation aided very materially in the presentation of this paper.

BOOK REVIEWS

Airships Past and Present. By A. Hildebrandt, Captain and Instructor in the Prussian Balloon Corps. Translated by W. H. Story. D. Van Nostrand Co., New York. 1908. Cloth, 6 by 9 ins.; pp. 364, including index; 222 illustrations. Price, $3.50 net.

Reviewed by Mr. O. Chanute, M. W. S. E.

Great advances have been made within the last few years in solving the various problems which pertain to aerial navigation. Dirigible balloons have been developed to fair speeds and efficiency and most European nations are building military airships, while practicable flying machines seem to be near at hand. Hence the public, hitherto languid, has become interested in learning authoritatively what has hitherto been accomplished.

Captain A. Hildebrandt is Instructor in the Prussian Balloon Corps. He has much experience and knowledge and has produced a book in German which proved so good that it has been translated into English, this appearing to be well done. There have been hitherto no sufficient English books on this subject and persons who desired to be informed had to refer to technical magazines. Captain Hildebrandt's book is intentionally of a more popular character, he stating in his preface that theoretical investigations have been reduced to the smallest possible limits in order not to frighten the reader. He gives, nevertheless, a few valuable formulæ.

There are 26 chapters, of which the first is a rather meagre early history of the art, but the next two treat of the invention of the hot air balloon and its development. These chapters seem to have been chiefly compiled from French sources and are fairly complete, but there are a few indications of haste in the compilation. Chapter IV explains the theory of the balloon, is very well written and, without going into details, gives the laymen an idea of the principles involved. The next four chapters describe the development of the dirigible balloon, from that designed by General Meusnier in 1784 to that of Count de la Vaulx at the beginning of 1906; giving illustrations and descriptions of the dirigibles of Giffard (1852-1855), who first applied an artificial motor and obtained a speed of 7 miles an hour, to those of Lebaudy, which had reached 22 miles per hour in 1906, speed being the one important element and the one in which great advance had been made since the book was written, so that a new edition will soon be required. A misprint occurs on page 63; the length of Count Zeppelin's second airship being stated as 85 feet instead of 414 feet.

The next (Chapter IX) treats of flying machines and is not very thorough. The reader will be probably puzzled by the statement on page 93, that Leger's screws produced a tractive force of 240 pounds with 6 horse-power, while Dufaux propellers produced a pull of but 14 pounds with 3 horse-power, no explanation being given that this is due to the amount of loading on the blades, the Leger screws carrying neither the weight of the apparatus nor that of the motor nor that of the aviator. On page 95 it is said that Santos Dumont's aeroplane travelled 200 feet, while in point of fact it was 220 metres. Also that Maxim's experiments were carried out with the assistance of Professor Langley, which is a mistake.

Chapter X on kites is good but mentions Marvin as connected with Blue Hill Observatory, whereas he is in the Weather Bureau, and Cody, of British kite fame, as "otherwise known as Buffalo Bill," whereas they are cousins. All of these are trifling slips of the pen, mentioned merely to show that the reviewer has read this interesting book. The next four pages on parachutes dismisses them as merely suitable for country shows, but the following two

chapters "The Development of Military Ballooning" and "Ballooning in the Franco-Prussian War" are very good and give a resume of what has been hitherto done. The most thorough chapters in the book are XIV and XV on "Modern Organization of Military Ballooning" in various countries, this, of course, being the author's specialty. And then after describing "Balloon Construction" he passes to the subject of "Instruments," explaining their character and use. "Ballooning as a Sport" next follows, Captain Hildebrandt giving some interesting accounts of his own experiences, which have been numerous.

Chapter XIX is on "Scientific Ballooning" to determine the laws of decrease of pressure, of temperature changes, of saturation with moisture, of the composition of the air, its electrical and its accoustical properties, and in ascertaining these points a number of the Scientists have lost their lives by venturing too high, the greatest elevation attained by man having been 35,500 feet, while kites have gone up to 21,100 feet, and unmounted balloons, with recording instruments (Ballons sonde) have reached 85,000 feet (16.1 miles) and are now chiefly used. The next six chapters treat of balloon photography, of the outfit required, of the interpretation of the photographs, of the use which can be made of kites and of the methods by which these bird's eye views can be interpreted for topographical purposes, in all of which the author is evidently an expert. He has also had much experience with carrier pigeons and devotes a chapter to them containing many useful hints. The reader will probably be surprised at the statement that the mean speeds of these birds is 26 miles an hour, as in the feats mentioned in sporting books it is much more, the pigeons on such occasions being probably greatly assisted by the wind. Indeed Captain Hildebrandt describes a case in which a swallow, separated from its mate, flew 150 miles in 2 hours and 16 minutes (70 miles an hour), but he does not say which way the wind blew.

The last chapter is on "Balloon Law" and is necessarily brief as such law can hardly be said to exist. The author points out "that some sort of international regulation will be necessary in the future, seeing that balloons are now much more common than they were and that the dirigible airship is a practicable possibility." Much, very much, has been accomplished since these lines were written in 1906.

THE STANDARD HANDBOOK FOR ELECTRICAL ENGINEERS. Flexible leather binding. 4 by 6¾ ins.; 1,283 pp., including a full and copious index of over 50 pp., many tables and statistics and some 1,300 illustrations. McGraw Publishing Co., New York, 1908. Price $4.00.

As its title indicates, this is a book containing such data and other information required by Electrical Engineers. It is not intended to cover absolutely all of the uses to which electricity is put, but the general field is well treated and the book contains a fund of information not found elsewhere. The volume is divided into sections or books averaging about seventy pages each, in which are grouped the various important items. Thus, section one is devoted to electrical units; the fundamentals of electric circuits are treated in the second section, and a third covers measurements and measuring apparatus. A section devoted to properties of materials used in the electrical industries will be found of great usefulness. A large variety of materials found in commerce are mentioned and described. The list of insulating materials is quite extensive though necessarily incomplete, as this field is constantly receiving new acquisitions.

Other sections on Magnets, Transformers, Generators, Motors and Batteries follow, the theory, design and operation of this apparatus being clearly explained.

Central Stations form another section in which water power stations, steam engines, turbines, gas engines and gas producers are all described, as well as switchboard, bus bar and switching arrangements. This is followed by a section on transmission and distribution, in which methods for calculating transmission lines and distribution systems are given, as well as the general design and operation of mechanical transmission.

An up-to-date chapter on illumination covers this interesting field quite thoroughly.

Electric traction, electro chemistry, telephony, telegraphy and miscellaneous applications of electrical energy each receive its section. In the latter, data is given for the application of electricity to machines, tools, pumps, cranes, hoists and other power uses. A section on wiring contains the usual description of wiring methods and distribution systems, together with wiring calculations for various purposes. The standardization report of the A. I. E. E., together with a synopsis of the National Electric Code and standard symbols are given in another section. The concluding section is devoted to tables and statistics.

The above parts have been compiled by a staff of specialists, each of whom has had considerable experience in the lines treated of by him. The result is that the book contains reliable data which is offered to the reader in concise and methodical form. The mechanical construction of the book is excellent. The cover is perfectly flexible and the paper of good quality. Altogether the book will be found a valuable addition to any Electrical Engineer's library.

S.

Gas Power: By F. E. Junge, Mem. Verein Deutscher Ingenieure, New York, 1908. Hill Publishing Co. 6 by 9 ins., 548 pp., including 14 pp. index; 7 folding plates; 160 illustrations, many tables, etc. "A Study of the evolution of Gas Power, the design and construction of large gas engines in Europe, the application of gas power to various industries and the rational utilization of low grade fuels."

This is the latest and probably the best addition to gas engine literature. While it deals mostly with the latest European practice, it describes successful engines, and is for this reason a most valuable treatise, and of special interest to the gas engine builder, as well as to the user of internal combustion engines.

The first part of the work is a treatise on the evolution of power, describing the reasons why gas engines are becoming more important prime movers.

Part second contains seven chapters on the design and operation of the well known types of European engines, showing the advantages or special features of each, also views of prominent authors, both here and abroad, on the gas engine situation and the proper methods of governing.

Part three describes the application of gas engine power in the iron and steel industries and the utilization of low grade fuels.

Free from higher mathematics and written in a clear and concise manner, the book should be in the hands of every manufacturer and student interested in prime movers.

C. E. S.

The Plane Table, and its Use in Surveying: By W. H. Lovell, Topographer, U. S. Geological Survey. 45 pages. 4¾x7½ ins. 9 ills. $1.00. Published by McGraw Publishing Company, New York. 1908.

Of course this book being written by a plane tabler in the employ of the Government makes the Plane Table out as a universal surveying instrument. The men employed in topographical work by the U. S. Government do not seemingly understand that the object of all surveying is not always to make maps; also that much surveying is done to an accuracy practically impossible of attainment by the methods of the plane table. Plane table work is accurate only for the scale employed and when the map must be reduced. When an enlargement is required the error increases rapidly and no surveyor's work is altogether free from error.

For many surveys the plane table is unequalled for rapidity and convenience; the reviewer has used the plane table a great deal in his own work, and its advantages are not doubted, but that it is to be used much more widely in the future than it has been in the past is questionable. The transit with stadia is too handy and has the advantage that if the party for whom the work was done suddenly decides to have maps made on a larger scale (as happens often in private practice), then the degree of accuracy of the new map will be as great as that of the first one. Where the plane table is especially adapted, if

compared with transit and stadia, there can be no comparison drawn, for the plane table is far more rapid and owing to the time thus saved (and consequent expense) it possesses a great advantage. In the end all work must measure up to the dollar standard.

The writer of this little book has done his work nicely, and for a man who has begun plane table work without having already in his possession a treatise on the subject, it should be of service. Even men of experience will find it useful and it is to the man who has used the plane table a little, that the book will no doubt appeal most. The book is of a handy pocket size and the matter may be worth the price, but when compared with the books in some other series it looks high-priced. McC.

MUNICIPAL OWNERSHIP: Four lectures delivered at Harvard University in 1907 by Leonard Darwin. E. P. Dutton & Co., New York. 1908. Cloth, 5 by 7¼ ins. pp. 197. Price $1.25 net.

The author of this very interesting book is the fourth son of the notable Charles Darwin, the naturalist, author of the "Descent of Man," etc. Mr. Leonard Darwin was born in 1850, educated at the Royal Military Academy, Woolwich (England), and for a time was in the Corps of the Royal Engineers. He was sent to take observations of the transit of Venus in 1874 and again in 1882; he was in the War Office from 1885 to 1890, and was a Member of Parliament from 1892 to 1895. He is the author of "Bi-metallism," published in 1898, and of "Municipal Trade," which came out in 1903. Being the son of such a father it is to be expected that he would possess a brilliant mind and be a fine writer, though one would hardly have expected that with a military training and some years of experience in the Royal Engineers Corps he would show such a logical mind, and such power in presenting his strong arguments against the idea of what we call Municipal Ownership. For those who are laboring under the delusion that many of the evils of present day management of the public utilities can be corrected by turning them over to be managed by the municipal authorities, this book is to be heartily commended.

Lecture I, considers that "ownership is not the main question," but that the vital point is—when should labor be directly employed by municipalities? "The Regulation of Private Industry" is of importance, as municipal monopolies must be controlled for the sake of the consumer as well as the tax payer; "with well considered franchises private industry can be efficiently controlled," but "the terms of franchises must be sufficiently liberal," and "further reform of the laws affecting municipal monopolies in private hands is much needed" both here and in England. "Municipal ownership and local taxation" is a financial question that is of the first consideration, and it has not been "directly proved that English cities, under much municipal ownership, are more or less heavily taxed than other towns with but little municipal ownership."

Lecture II, takes up the subjects of "Municipal Statistics," "Price and Quality," with "*A Priori* Arguments," and "Financial Conclusions." "No great gain is made by municipal ownership in England, and general financial considerations are against the direct employment of labor by Municipalities."

Lecture III, takes up the questions of "Municipal Corruption," the "Wages in Municipal Industries," and "The Case of Direct Employment;" as, for instance, public water supply.

Lecture IV, on "Municipal Ownership," is a summing up of the arguments, with the following main objections: The national dividend will be diminished, and municipal indebtedness will be increased; there is a lack of initiative in municipal management, and there is a tendency for industries to become monopolies. Finally, "At present we should study existing municipal industries before adding largely to their number."

The book is solid reading, though full of interest to those who have a taste for sociological study, and to all concerned in this important present day question. W.

LIBRARY NOTES.

BOOKS PURCHASED.

North-American Railroads; Official German Report. 1906
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Church, Irving P., "Hydraulic Motors."
Creighton, W. H. P., "The Steam Engines and other Heat Motors."
Fanning, J. T., "Hydraulic and Water-Supply Engineering."
Flemer, J. A., "Photographic Methods and Instruments."
Goss, Wm. F. M., "Locomotive Performance."
Herrick, Rufus F., "Denatured or Industrial Alcohol."
Hoyt, John C. and Nathan Clifford Grover, "River Discharge."
Hutchinson, Rollin W., Jr., "Long Distance Electric Power Transmission."
Kershaw, J. B. C., "Fuel, Water & Gas Analysis."
Koester, Frank, "Steam-Electric Power Plants."
Latta, M. Nisbet, "American Gas-Engineering Practice."
Lea, F. C., "Hydraulics."
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Peters, Edward D., "Principles of Copper Smelting."
Richards, R. H., "Ore Dressing." (Vols. I and II).
Vernon-Harcourt, L. F., "Sanitary Engineering, (Water Supply and Sewage Disposal."
Weed, Walter H., "The Copper Mines of the World."
Wilson, G. B., "Air Conditioning."

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Extra Meeting—3rd Wednesday evening of each month except July and August.

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Board of Direction—The Tuesday preceding the 1st Wednesday of each month.

NOTICE

From the dues of each member, $2.00 is set aside as a subscription to the Journal.

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SOME FEATURES OF CONSTRUCTION OF THE SOUTH SIDE ELEVATED RAILROAD

MR. J. N. DARLING, M.W.S.E.

Presented March 25, 1908.

The South Side Elevated Railroad Co., in order to meet the requirements of a rapidly increasing population within the limits of the territory covered by its line, has recently been making some extensive improvements in its existing line, as well as building several extensions into new territory in the southern part of the city.

The original line was built as a two-track structure southward from Congress St. to 63rd St. and eastward in that street to Jackson Park.

At the time when this original line was built (in the early 90's) the portion of the city which it traversed, especially from 39th St. southward, was rather thinly inhabited; the only immediate incentive for building so far southward at that time seeming to have been to reach the World's Fair traffic of 1893.

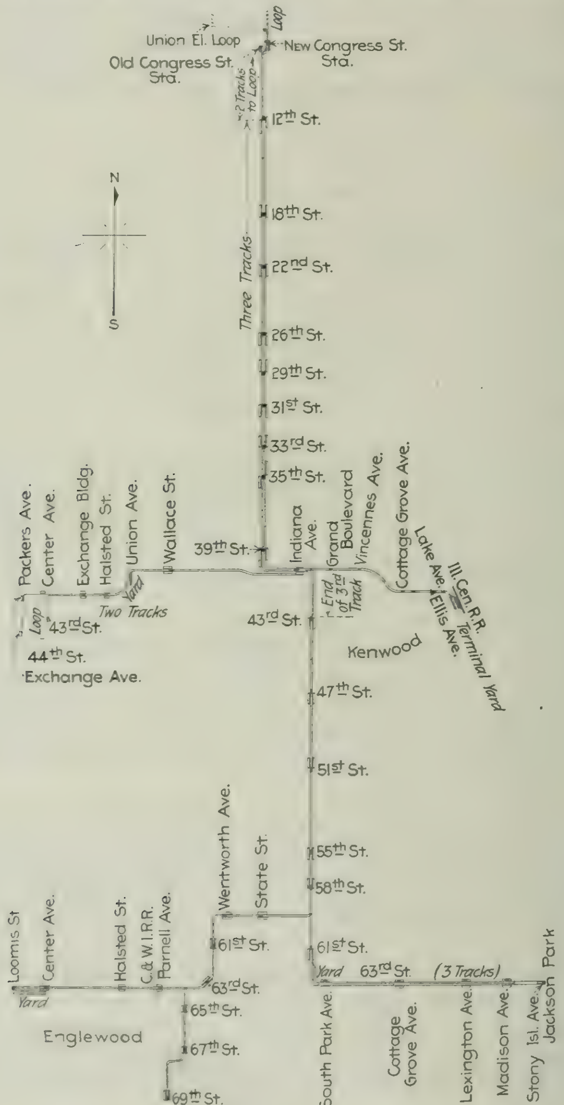
Following the construction of this line, however, owing to the exceptional transportation facilities which it afforded, the population contiguous to it, steadily and constantly increased with the years until finally it reached a point where, if additional facilities for a more rapid transit to the business center of the city were not provided, this increase of population would be checked, or the natural and normal growth would seek some other line or lines of transportation.

To meet these constantly increasing transportation requirements, it was finally decided to add a third track to the existing structure between 12th and 43rd Sts.; to eliminate existing sharp curvatures at several points, and to make several other important improvements, the nature and scope of which will be further described in this paper.

This additional third track, which was accordingly built, is used for local service, leaving the old east track (now the middle track) for express service, to afford the large patronage originating south of 43rd St. a rapid transit to and from the downtown district,—it being used for north bound traffic during the rush hours of the

morning and for south bound traffic during the corresponding rush hours of the evening.

The original two-track structure from 12th St. southward to 63rd St. was built on private right-of-way—a 25 ft. strip cut from the rear end of the lots adjoining alleys: in order to widen the structure for the third track without making a further and expensive cut into



General map of South Side Elevated Railroad.

the private properties, it became desirable to acquire the use of the adjacent alley for the extended width.

Franchise for this use, was accordingly sought and acquired, and the alley was, in general, used for the addition. But, as a compensation for the privilege thus acquired, the South Side Elevated Railroad Co. was required, by the terms of the grant, to pave with asphalt its entire right-of-way and the alley adjacent, from 12th St. to 43rd St., and to throw the whole strip (40 ft. and more in width) open to the public for use as a thoroughfare, the Company merely reserving the fee to its own private right-of-way.

This requirement made necessary several other very important and expensive features of the work of improvement; namely, tearing away all the old stations, which, in the original construction were built on the ground; building new stations suspended from the structure with 14 ft. clearance above asphalt grade; and, finally, raising the existing structure at all stations to a height that would allow of the building of the station underneath, with this required clearance. A description of some of the interesting features of this work will be given later.

In addition to the work above enumerated, a two-track structure (now in operation) has been built into and through the thickly settled portion of Englewood, extending from the old line (as shown on accompanying diagram) at 59th St., west, south and west to 63rd and Loomis Sts., with terminal yards of seven tracks in width extending from Center Ave. to Loomis St.

Also a South Branch, extending from the above extension at 63rd St. and Stewart Ave. southward to 69th St. near Parnell Ave. The total length of the Englewood extensions being about 3½ miles.

Also, through arrangements with the Chicago Junction Railway Company, an extension has been made eastward in 40th St. to the thickly settled portion of Kenwood, with a terminus at 42nd St. and Oakenwald Ave. near the lake. This extension, 1¼ miles in length, is now in service and is operated on the elevated roadbed of the Chicago Junction Railway Company.

Also, by an arrangement with the same Company, a western extension of steel structure has been built in 40th St., joining the Main line of the South Side Elevated Railroad at Indiana Ave. and 40th St. and extending west to the Stock Yards with a Loop in the Yards. This extension, except the portion between Wentworth Ave. and Wallace St., adjoins the Chicago Junction Railway on the south. Between the two streets mentioned, however, the Elevated Structure is directly over the tracks of the Junction line, being built of cross-girder construction with columns supported on the retaining walls of the elevated roadbed of that line. This extension is now practically complete and will soon be put into service.

As a necessary part of the extensions and improvements above enumerated, the old terminal yards at 61st St. and Calumet Ave., originally on wooden trestle, have been entirely rebuilt of steel on

concrete foundations; an extensive surface terminal yard has been built south of 63rd St., between Calumet and Prairie Aves., with an incline leading thereto; a large increase of power has been installed at the Power House at 39th and State Sts., and interlocking and block signals have been installed.

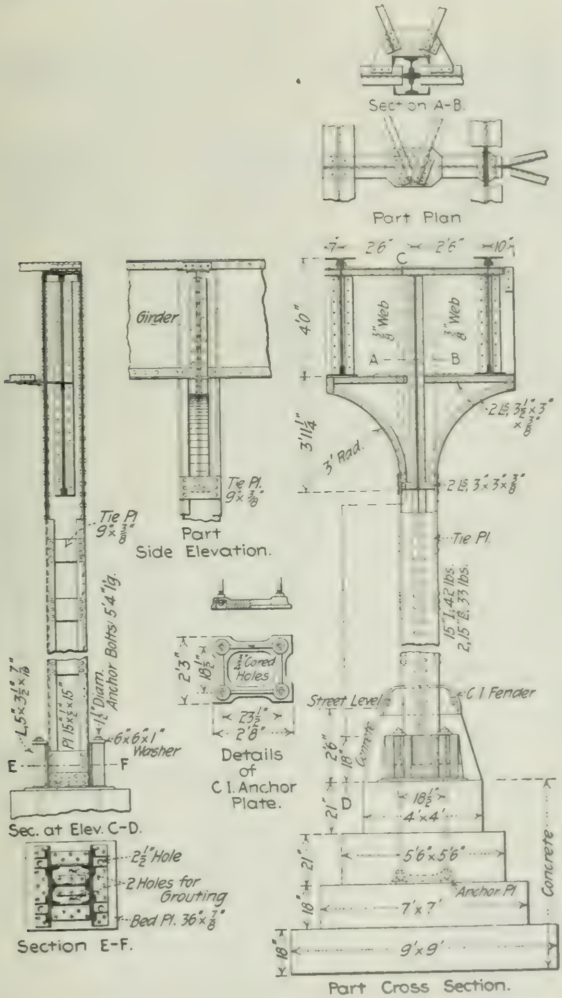
Structure on temporary blocking while elevating to new grade.

None of the work above enumerated presents any special or unusual engineering features, except the work of adding the new third track to the existing structure, embodied with which, as a necessary part of it, being the raising of the existing structure to the new grades required (from 3 to 6 and even 8 feet above the old grade); the changing of the existing alignment to eliminate sharp curvature, involving at many points entirely new construction; the tearing down of the old stations and building the new ones; and all the allied details of the work necessary to produce from the old structure the remodeled and extended and fully equipped structure as it exists today.

All this work had to be carried on in regular progression, and in such a way as not to interfere materially with the comfort and convenience of the traveling public; and under a train service of over 600 trains daily, with intervals of from one to three and one-half minutes. To meet these conditions and to prevent disaster or accident, the greatest care both in design and execution was necessary. To describe some of the more important and difficult features of this rather unusual piece of work, is the design of this paper, the novel

character of the work constituting the warrant and excuse for this presentation.

In the entire work from 12th St. to 43rd St., designated as "Third Track" construction, about 660 new concrete foundations were required, 430 of which were for new Third Track and 230 were for renewals of old foundations, at station points and elsewhere, where changed conditions due to new construction called for a larger foundation support.

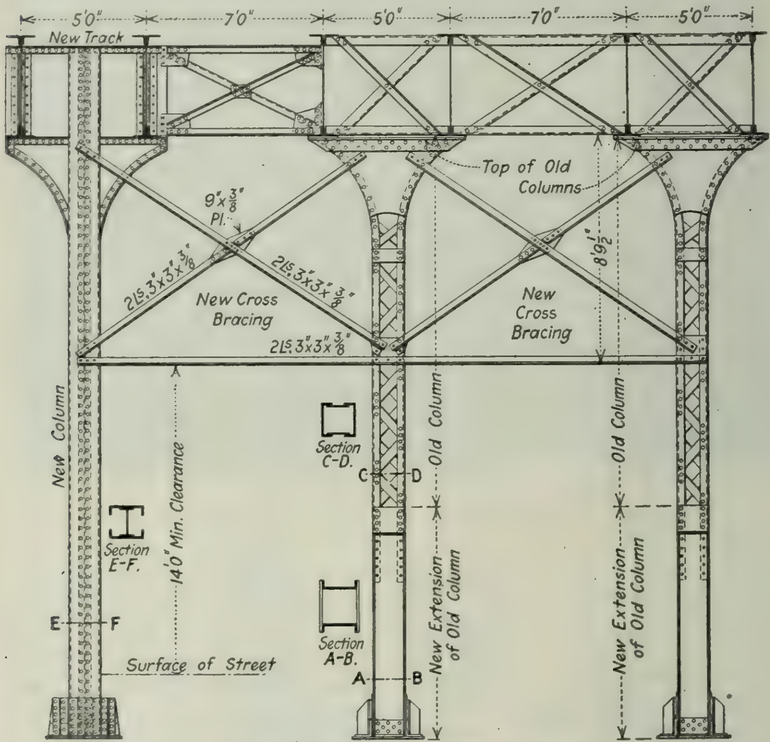


New third track column with enlarged foundation.

The old foundations were 7 ft. by 7 ft. in the bottom course while the new ones, in general, are 9 ft. by 9 ft.—thus affording a much larger supporting surface. As constructed the entire weight carried per foundation is approximately:

For Carload	72,000 lbs.
Structure	41,000 lbs.
Foundation	14,000 lbs.

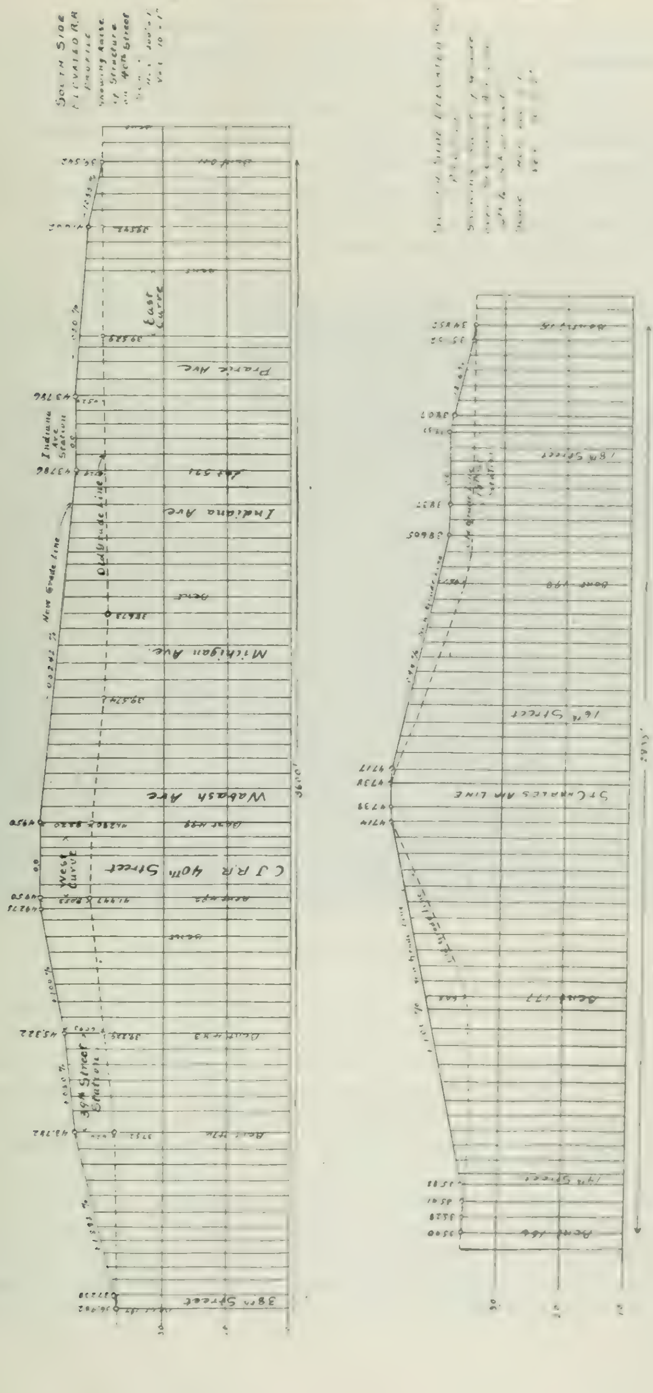
or a total of 127,000 lbs.—an approximate load of 1,600 lbs. per square foot on the underlying earth.



Construction for three tracks, with one new column and cross bracing.

The 430 foundations for the Third Track were first put in, for the most part, in the fall of 1904 and the season of 1905. The foundations for renewals under the old structure were put in simultaneously with the blocking and jacking-up of the old structure.

One of the most extensive elevations of the old structure was from 14th St. southward over the "St. Charles Air Line" and on past 18th St. station, a distance of 2,800 feet. When the St. Charles Air Line was elevated, several years since, the South Side Elevated Railroad Co. raised its structure to give the necessary clearance.



Profiles of parts of South Side Elevated Railroad.

This raise was 13 feet at the "Air Line" with approaches of 2.17% grade, the columns being spliced to give the proper elevation. In the new raise an approach of 1% was given each way, beginning at about 14th St. on the north, as stated, meeting the old summit at the St. Charles Air Line, then running off on a 1% grade till the level required for 18th St. station was reached, thence running a level grade past the station platforms, and thence on a 1% grade to the original elevation at a point south of the station. The maximum raise to attain the new elevation was 6.58 feet.

Charging from 2 track to 3 track structure at 14th street, looking north.

The work of this elevation was commenced in December, 1904, and carried forward continuously to completion. New column extensions were riveted in place as fast as the jacking was completed, the old extensions being removed and used in other places where the additional elevation was such as to allow of their use.

At a point just south of 14th St., the old structure crossed from the east to the west side of the alley with a sharp curvature which was to be eased off at a later date in connection with the erection of the Third Track structure, which changed sides at this point. To provide for the necessary reconstruction for this, the structure was left on its blocking at this point. Also at the 18th St. station, where future reconstruction was necessary, the blocking was left in.

Elsewhere, as fast as the column extensions were riveted in place, the old structure was "landed" and the blocking was removed, leaving the old structure ready to receive the new third track.

At the several stations south from 18th St. the structure was similarly raised, attaining the required elevation opposite the station platforms with approaches of 1% each way. The elevation required at the stations, in general, ranged from $3\frac{1}{2}$ to $4\frac{1}{2}$ feet additional, requiring a stretch of from 800 to 1200 feet to make the elevation.

The work of elevation on 40th St., however, (which includes the 39th and Indiana Ave. stations) was exceptional, as between these two stations the elevated railroad crosses the Chicago Junction Railway, which also was elevating its tracks and required a raise of the elevated railroad structure of 8 feet for clearance.

To provide for this, and for the elevation at each of the stations mentioned, required one continuous stretch of elevation beginning at 38th St. at the foot of the north incline, attaining the required elevation at the north end of 39th St. station platforms, thence level past the platforms, thence up over the Chicago Junction road, thence descending slightly along 40th St. to a level grade past the platforms of Indiana Ave. station and so on, meeting the old grade of the structure at the south end of the curve at 40th St. and Calumet Ave.—a total length of raise of approximately 3100 feet.

Combined with this elevation there was also an easement in the alignment of both the east and west curves at 40th St., involving a new structure throughout as well as the necessary reconstruction at each station. The principal features of this complicated piece of work will be considered later on.

The blocking used in raising and supporting the structure was, in general, built up as follows: a practically continuous floor of 4 in. by 4 in. timbers was carefully leveled on the ground, on which was built a crib work of 12 in. by 12 in. timbers, laid "cob house" fashion, about 6 feet high, surmounted by a pair of trestle bents of 12 in. by 12 in. timbers of such a height as to reach the track girders, or cross-girders, as the case might be.

The crib work was built with eight of the 12 in. by 12 in. pieces projecting—four directly above the other four, forming an intervening space for the 30-ton hydraulic jacks used in raising the structure.

The working of the jacks in this space divided the crib work by a constantly increasing interval which was kept filled in by one and two-inch planks and by wedges till the interval thus created amounted to 12 inches, when the thin pieces were discarded and an additional 12 in. by 12 in. piece was inserted to fill the space. A 12 in. by 12 in. stick was then placed across the lower projecting ends to raise the jacks. The process was then repeated, and thus the work was continued till the proper height was attained.

One set of four jacks was used, raising one track at a time about 3 inches at a lift, if of center column structure, or 2 inches, if of

cross-girder structure, was being raised. Each lift of one track was followed by a corresponding lift of the other track and so the two were carried up together.

With center column structure, no difficulty was experienced in handling one side at a time, but with cross-girder construction, a two-inch raise at a time was about the possible limit, and even at that, a few hitch angles were broken and afterwards replaced.

This work was all done under slow orders for trains with a flagman on top to stop trains, if necessary, till the amount raised could be caught and the jacks released, as the jacks would not stand the impact of trains.

This work was all so carefully and expeditiously handled that trains were rarely held more than a minute or two. No jacking was done during the "rush" hours of morning or evening, the train interval when the work was going on, usually being 2½ or 3 minutes.

Where new foundations were to be put in, to replace the old, instead of the lower course of 12 in. by 12 in. 10 ft. timbers, six 8 in. by 16 in. 30 ft. pieces were used for blocking, so as to span the required foundation excavation by a safe margin. These timbers were so spread as to give space for removing the old foundation and putting in the new, which work was all done while the structure was carried on this temporary support.

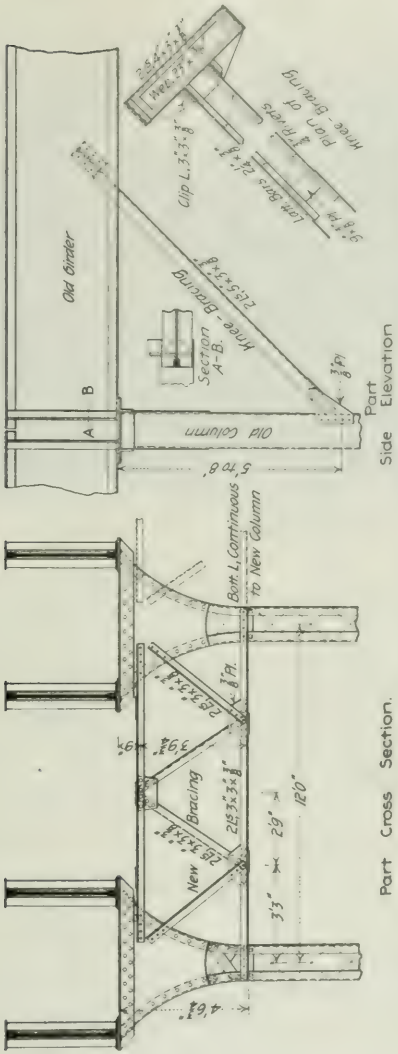
After the structure was carried to its full height, the old foot castings used in the original construction were knocked off by rammers dropped from a height of three or four feet, and new column extensions of suitable length, built up of 15-inch channels and plates, were riveted to place and anchored, after which the blocking was removed.

The additional height of the columns, due to the splicing, required additional strengthening to give the required rigidity to the structure. This was effected by a system of knee and cross-bracing at the top, so placed as not to interfere with the required headroom of 14 feet.

At each one of the old stations there was one bent of the old structure situated within the building, and in order to raise the structure and at the same time keep the old station in operation as long as possible, it was necessary to tear out a portion of the building and make temporary changes in the stairways so as to make the necessary space for blocking at the columns and to make the necessary renewals of foundations.

No two stations were alike and the difficulties encountered in making these changes required special devices in each case, but they were successfully met and overcome and the public was, in all cases, suitably provided for, during the progress of this feature of the work.

As soon as the raising of the existing structure past a station was completed, the method of procedure was to erect at once a small temporary station across the street from the old station, with land-

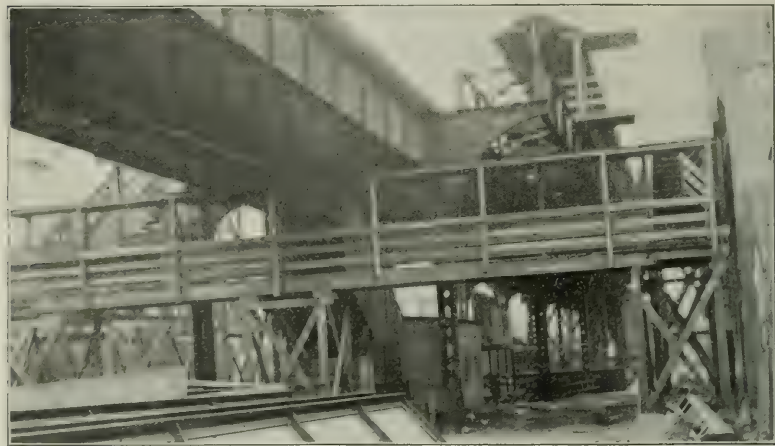


Original spread top column construction with additional cross and longitudinal bracing where columns are extended.

ings and stairway connection with the station platforms, usually at the very end of the platforms. Traffic was then diverted to the temporary station, the old station was wrecked and space was cleared for the erection of new suspended station.

Meanwhile the third track structure had been erected on either side of the station and the track laid up to the station platform. The space which carries the new station consists of through girders in

order to give the necessary headroom for the station, requiring two entirely new bents on new foundations.



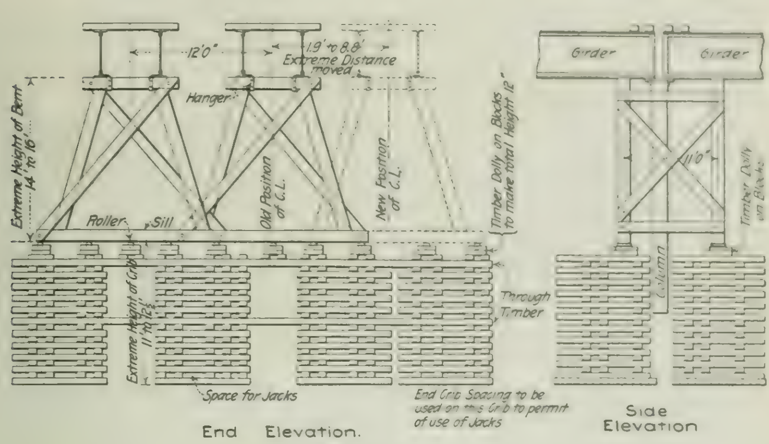
Temporary station and landing.

For this reconstruction, the blocking supporting the existing structure had been left in place. The track stringers on either side of this station span are now cut loose and cut off sufficiently to allow for the insertion of the new cross-girders, the new supporting columns are new erected from beneath and the cross-girders are launched endwise to place and riveted to the columns. Track stringers on either side of the reconstructed span are now riveted to the cross-girders, new hitch angles being provided for the purpose. Meanwhile crossovers have been installed between the two old tracks on either side of and beyond the limits of the station platforms.

Up to this time normal movement of trains has not been interfered with. At this stage, however, the west track between the two crossovers is abandoned, all traffic being diverted to the east platform. Old track and timber on the abandoned portion is now torn out and relaid with new material, old track girders of the west track at the station span are removed, new through girders are erected and riveted and new track is laid over the bridge to connection.

Double-track service is now temporarily resumed during which crossovers are interchanged preparatory to single-track movement on the other track, a process requiring usually three or four days. Single-track service is now installed on the west track; the old east track being torn up and relaid with new material. The remaining through girders of the station span are erected. The east platform is now jacked over 12 feet eastward onto brackets extending from the new third track columns. Middle and east tracks are laid

through the bridge to a connection, and a temporary stairway, leading up to the east platform is adjusted to new connection. Two-track service is now permanently installed on the two outer tracks, leaving the middle track for future use in express service.



Cribbing and moving old structure laterally.

The suspended steel structure for the support of the new station is next erected, and the new station with landings and stairways is built entirely without hindrance to traffic, as the temporary station is maintained till the permanent station is entirely ready for use.

The occupancy of the permanent station with the demolition of the temporary one marks the completion of the work at any given station point.

The erection of the steel work at a station, and the construction of the station ready for occupancy usually required from sixty to ninety days.

Reconstruction on 40th St.

Special mention has been made of the reconstruction along 40th St. as involving many difficult features not encountered elsewhere on the work.

The old two-track structure at the east and west curves was built with radii of 100 feet, necessitating very slow movement of trains. An elimination of this undesirable feature was important, and a part of the work of reconstruction of this portion of the line was made to comprise an entire reconstruction of these two curves with radii of 182 feet in the central portion, compounding with curves of 500 ft. radius at the ends.

In order to secure the required curvature at the west curve, local conditions made it necessary to cut across the old structure in 40th

St., and to end the new construction at the east end of the new curve about 6 feet south of the old alignment in 40th St.; making it necessary to jack-over the old structure onto new foundations to meet the new structure, and to introduce curvature of easy radius at the pivotal point of this movement just west of Michigan Ave.

The course of procedure for the entire work of reconstruction of this portion of the line beginning at 38th St. and ending at the south end of the east curve in the alley between Prairie and Calumet Aves. was essentially as follows:

During the month of February, 1905, the old two-track structure was jacked-up to its new elevation 6 feet above old grade through 39th St. station with its permanent run-off northward to 38th St. and with a temporary run-off southward toward 40th St. Column extensions north of the station were riveted in place, the structure was landed and blocking removed, except at the station where the structure was left on its blocking to await future reconstruction at that point. The structure for the extent of the temporary run-off was also left on its blocking to be used in a further raise at a later stage of the work.

While this work was going on, new foundations were being put in for the change of line at the east curve. The existing structure at the east curves was now jacked-up to the grade established for the reconstructed line at that point, the elevation beginning at a point about 300 feet south of the south end of the old curvature, extending, at the established grade, past the platforms of Indiana Ave. station and ending, at this stage, in a temporary incline west of the station. The maximum raise—namely: opposite the station platform was 4.7 feet.

Following the jacking-up, column extensions were riveted to the columns that were to remain in the work and that portion of the structure that was to be replaced with new structure was left on its blocking.

Meanwhile the new Third Track structure, on the east side of the old, from 43rd St. to the south end of the new curve was erected. Next all that portion of the new east curve that could be put up without interference with the old structure and with the operation of trains was erected on its new foundations, and, at the same time, track was being laid on the new Third Track structure between 43rd St. and the south end of the new curve.

The new south bound track from the east end of the platform at Indiana Ave. station around over the new structure was also laid ready for a connection.

Up to this point, traffic on the two old tracks had not been disturbed, but reconstruction had now reached a point when traffic must be diverted in order to continue the work. Accordingly single-track service was now installed over the old north bound track between crossover No. 4, just east of the station and crossover No. 8, just south of bent No. 537, (Fig. A large plate), where new and

old construction were to be joined—south bound trains running in the face of north bound between these crossovers.

During this movement of trains, the old south bound track and structure around the curve was torn out and the new south bound structure was connected with the old south bound, at bent No. 537, and new south bound track was laid to a connection with the old south bound at that point; and crossover No. 5 (Fig. B) was laid.

Two-track service was now resumed around the curve, north bound traffic continuing over old north bound track and south bound over new south bound, using crossover No. 5 as shown.

During this movement of trains crossovers No. 4 and No. 8 (shown in Fig. A) were interchanged right to left and left to right (as shown in Fig. C), and single-track movement over new south bound track around the curve was installed, leaving free the old track and structure between these crossovers.

The remainder of the old structure around the curve was now torn out and the new structure for the middle and north bound tracks was erected, and the track laid around the curve, except a gap between S and T (Fig. C) which could not be completed until traffic was completed between S and T (Fig. C), and through girders of the the station was now laid; crossover No. 4 (Fig. C.) was abandoned and the present single-track movement was extended westward through the station on the south bound track, using crossovers Nos. 10, 5 and 8 (Fig. D). During this movement, the structure and track was completed between S and T (Fig. C) and through girders of the

40th street, near west curve, with temporary trestle

north bound track at the station span were erected, the old track through the station was torn up and the new track laid.

Continuous double-track service was now again resumed (as shown in Fig. E), the middle and north bound tracks to 43rd St. being used. During this train movement the right-hand crossover just west of the station was changed to a left, and the crossover just east of the station connecting the middle and new south bound tracks was taken out, the situation being as shown in Fig. F.

West curve at 40th street, finished structure, looking southeast.

Single-track movement on the north bound track through the station was now installed over these crossovers. During this movement, the structure for the new south bound track was erected past the station, the south platform was jacked-over to its new position (Fig. F), the remaining through girders at the station span were erected, and the new south track was laid through the station.

While the above mentioned work was in progress, a temporary station had been erected at Prairie Ave. with temporary stairs leading up to the east end of the platforms. Traffic had been diverted to this and the old station at Indiana Ave. had been wrecked. On the site thus cleared, the new station was now erected on the steel work suspended from the structure at the through span.

Also, while these changes were in progress, the jacking-up of the

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New construction at west curve at 40th street.

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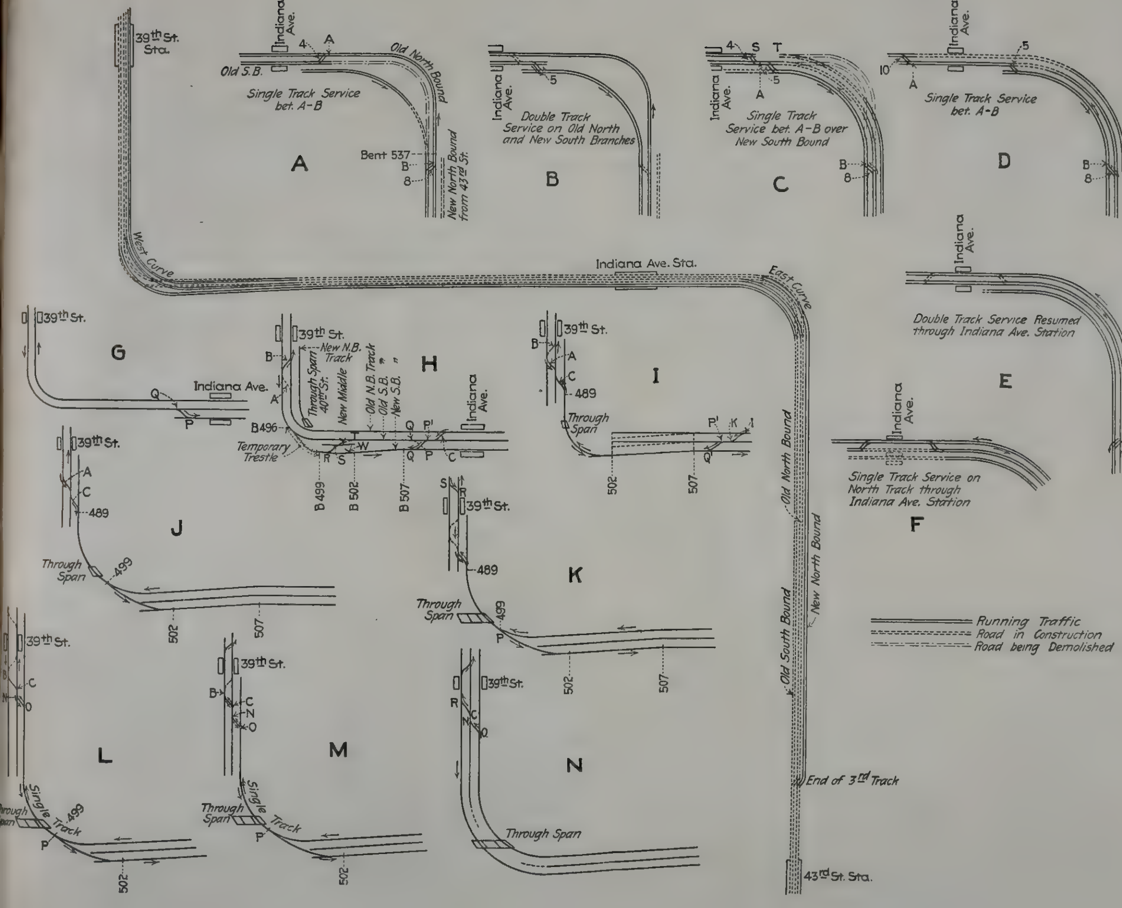
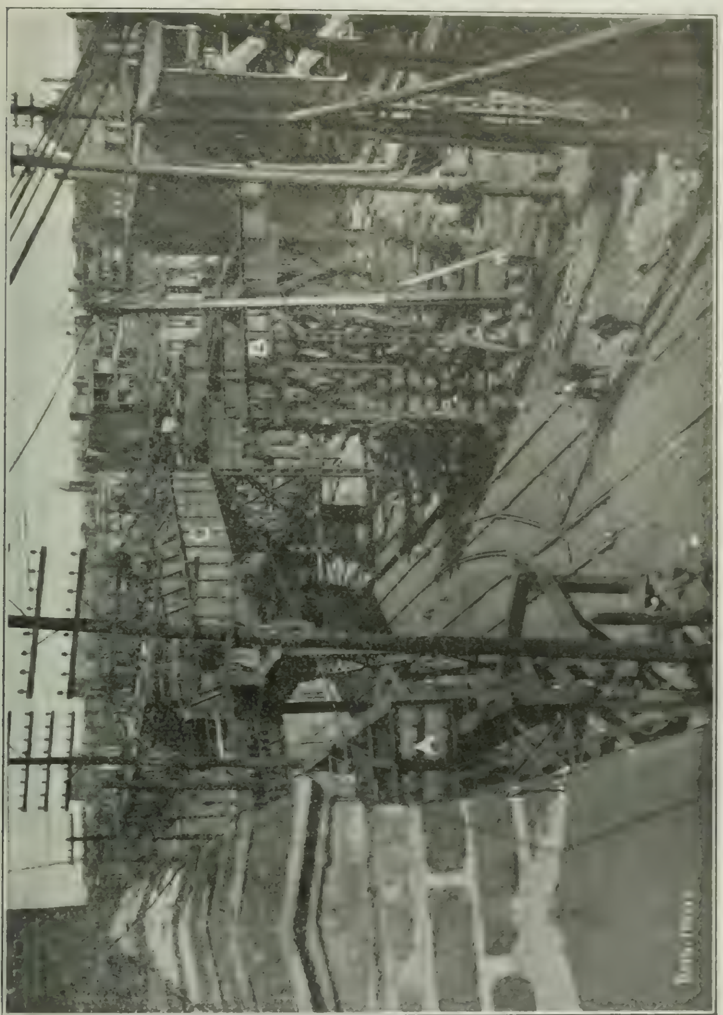


39th St. Sta.
Indiana Ave.
Old S.B.
Old North Bound
Single Track Service bet. A-B
Bent 537
New North Bound from 43rd St.
A
Double Track Service on Old North and New South Branches
B
Single Track Service bet. A-B over New South Bound
C
Single Track Service bet. A-B
D
West Curve
Indiana Ave. Sta.
East Curve
Double Track Service Resumed through Indiana Ave. Station
E
Single Track Service on North Track through Indiana Ave. Station
F
G
H
Through Span 40th St.
New N.B. Track
New Middle
Old N.B. Track
Old S.B.
New S.B.
Temporary Trestle
I
J
K
L
M
N
Through Span
Single Track
Old North Bound
New North Bound
Old South Bound
End of 3rd Track
43rd St. Sta.
Running Traffic
Road in Construction
Road being Demolished

old structure from Indiana Ave. to 39th St. had been carried steadily forward to completion.



New construction at west curve at 40th street.

All structural changes and additions from Indiana Ave. station southward, being now complete, final two-track service on the outer tracks from a point just west of Indiana Ave. to 43rd St. was now installed, the situation at this state being as shown in Fig. G, which shows the new track and structure completed to the point mentioned, with the crossover used in this service in position. The arrows in the figure indicate the train movements.

The erection of the new Third Track structure had now (July, 1905) been carried westward to bent No. 499 (shown on Fig. H), also the new middle track structure between bents Nos. 499 and 502 was erected. Also a temporary trestle outside of the existing structure from bent No. 496 to No. 499 (Fig. H) was erected to connect the old and new south bound tracks for temporary purposes of construction. Meanwhile tracklaying had been kept close up with the erection, and by Sunday, July 23rd, track was all laid over the new south bound track and temporary trestle ready for a connection at bent No. 496.

Temporary arrangement at station, 40th street and Prairie avenue.

To make this connection and at the same time to disconnect crossover Q.P. (Fig. G), Sunday was chosen, as comparatively few trains are run on that day. Accordingly in the forenoon of Sunday, track connection was made at the point mentioned and crossover Q.P. was removed from the south bound track. While this was being done all south bound trains were diverted to the north bound track at crossover A (Fig. H) and switched back to south bound track at 43rd St.

On the completion of this work, two-track service was immediately resumed, south bound trains now being run via temporary trestle and new south bound track southward.

Next, the middle track now being clear, by the use of the two outer tracks a portion of same west of T, near bent No. 502, is

swung over and connected with switch R.S. Single-track movement around the west curve is now installed, north bound trains passing via crossover C, T.S.R., the temporary trestle, and crossover B to their proper platform at 39th St. station; and south bound trains continuing via temporary trestle and new south bound track to Indiana Ave. station and southward. This movement leaves all the east portion of the old structure of the curve clear for tearing out and rebuilding.

During this single-track movement the following work was done: Completed erection of new east track structure from curve at 40th St. to south end of station platform at 39th St., (as shown on Fig. H), and erected through girders for new north bound track over Chicago Juction Railway at 40th St. Meanwhile all free old structure between bents No. 499 and No. 502 was torn down and new structure was erected in its place. Right-hand crossover Q.P. was changed to left, Q′.P′. on same location. New east track between 39th St. and bent No. 499, including that portion through the east through girder span, together with all other track that it was possible to lay was laid.

In order to get at the balance of the old curve and to erect the new, it now became necessary to abandon the crossover R.S.T. (Fig. H). This was effected by extending the single-track service to Q′.P′. just east of bent No. 507; R.S.T. was now taken out, and turnout W, just west of bent No. 502, was laid to a connection with the new north bound or east track, just south of the through girder span, with a switch inserted in line for the future or completed north bound track.

The work had now advanced to a point where another diversion of traffic was necessary in order to vacate the balance of the old structure at the curve. Accordingly on August 11, 1905, single-track movement was installed as shown (Fig. I), —south bound trains coming onto the single track via A and C, and north bound via I.K.P′.Q. This movement, as shown on figure, left the old two-track structure between bents No. 502 and No. 507 out of service and ready to be jacked-over to its new position parallel with the new Third Track and to a connection with the new three-track structure west of bent No. 502.

This work was now, accordingly, done, the structure having been left on its standard blocking on rollers provided for the purpose. The balance of the old curve structure was now torn out, the remaining through girders over the Chicago Junction Railway were erected as well as the remainder of the structure south of the through girder span.

The new north bound track was now laid westward on its permanent location to a connection with its corresponding track at bent No. 499, at the switch previously mentioned (Fig. J). On the completion of this connection single-track service was shortened up to this point from the east, greatly facilitating the handling of trains.

A left-hand crossover was now installed between the two old tracks just north of 39th St. station, for use during the reconstruction of that station. Single-track movement over east track at the station was now installed, extending from R to P, Fig. K; south bound coming on at S.R. and re-entering south bound track at P. The old west track was now torn up through past the station platforms; new through girders for the west track at the station span were erected, and new south bound track, south from the station was laid.

Double-track service through the station was now resumed, the single-track service being now limited to C.O.P., Fig. L.

During this movement the crossover north of the station was changed from left to right, whereupon single-track movement was diverted to south bound track at the station and combined with the continued single-track movement across 40th St., the single track movement now extending from V over crossovers B., C. and N.O. to P, Fig. M.

During this movement the new Third Track structure is erected northward past the station; through girders are erected for the middle and east tracks at the station span; and the east platform is jacked-over to its new position for the third track.

Meanwhile the south bound track has been laid to a connection with its corresponding track on 40th St., and now double-track service is immediately installed south of 39th St. on the two outer tracks (as shown in Fig. N), thus shortening the single-track service to the space between V and B at the station platform.

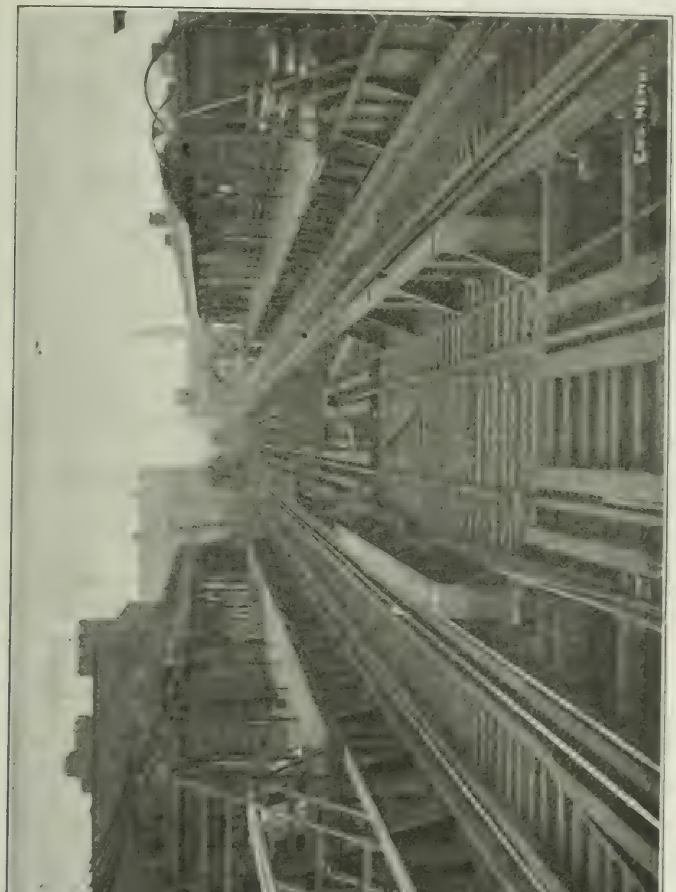
The new north bound track is now laid past the station to a connection with the corresponding track that has already been laid between 39th and 35th St. stations; and double-track service is now installed, thus making the operation of the third track continuous from 43rd St. to 35th St., and leaving the middle track between these points free for future express service.

The entire work of adding the third track, reconstructing the curves, raising the old structure, etc., from 38th to 43rd Sts., covered a period of about eight months—namely, from about February 1 to September 27, 1905.

This work being carried on as it was under traffic, involved many trying and difficult problems both of design and execution. Its essential features were so interrelated, so interdependent that no single phase of the work could be treated independently, but only with due regard to all its relations, and everything had to be carried out, in the field as in its design, as a part of a complicated whole.

As in the design and execution, so in a description, once commenced, there seemed to be no place for a pause until the end was reached. I have, therefore, even at the risk of tediousness and prolixity in detail, enumerated at some length all the essential details of this important and difficult piece of work—namely, from 38th to 43rd Sts.

I would add that in this as in all the rest of the work—adding the third track and the reconstruction of the old structure, the original plans and designs provided were not deviated from in any essential detail; and during the whole course of the work there was no accident and no serious inconvenience to the traveling public.



Typical view of reconstructed tracks at stations

In the earlier stages of the work, the question was often asked whether the waving grade adopted was to secure an advantage in the handling of trains, and a wish has been expressed that this paper

would deal with this feature of the work, to the end that the extent of this advantage, if any, might be brought out.

In answer to this, I would state that the grades as they stand today were established solely to secure the necessary headroom underneath; and that, whatever resulting advantage may have accrued, (which advantage would be confined exclusively to the movement of local trains) is merely incidental to the main consideration.

The amount of this advantage has not been, and probably cannot be, computed by any general mathematical formula, due to the existence of so many varying and limiting conditions such as,—the length of the level stretch on which the train is stopped, the varying position of the train on the level stretch, the length of the train, etc.

We know, of course, that the resistance due to a grade of 1% is 20 lbs. per ton of 2000 lbs., which resistance aids in the stopping of the train as it approaches the station and which also aids in the acquisition of maximum velocity on the 1% run-off when same is reached.

The initial current required to start the train on level track is a readily determinable quantity. If the head of the train at starting is at the beginning of the run-off, the advantage at starting is zero, and gradually increasing toward the 20 lbs. per ton till the entire train comes on to the incline, when the maximum saving of current is attained.

As is usually he case, however, the train stops at some intermediate point on the level stretch, in which event no saving of power is available in starting, such saving coming into play only after the train has acquired some velocity.

All these varying conditions are enumerated to show that any general formula to fit all cases would be impossible, or, at least, difficult to secure. This question, however, is an interesting one; and it is to be hoped that a discussion of this paper may bring out, as one of its features, some ideas that may tend toward a general solution of the problem if such is attainable.

DISCUSSION.

Mr. W. B. Storey, Jr., M.W.S.E.: This paper has been an extremely interesting one to me, and Mr. Darling has indicatel very clearly the difficulties that engineers have to meet in work of this character. I think the thanks of the Society are due the author for the very efficient way in which he has presented the subject to us.

Mr. Darling: In this connection I wish to say that I regret that I could not have furnished better material for illustrating the work on 40th Street.

Mr. J. C. Fruit: I might call attention to the difficulty experienced in the field in tying the new structure to the old. This tying together system, consisting of cross frames and laterals, was designed from the drawings of the old structures in conjunction with draw-

ings for the new. When the work had been fabricated and erection commenced it was found that the old structure had settled considerably out of line and that tying cross frames and laterals would not fit in the majority of the spans, necessitating new members for these spans.

Mr. Darling: Theoretically, the old structure was supposed to have some sort of standard and I presume it did, but as a matter of fact little irregularities had developed with the years, and it required special devices for about every span. This necessitated the connecting work to be furnished in blank and the drilling to be done to fit.

Mr. Storey: Was this work, as well as the work on the track and that which you have shown us in the way of changing switches, etc., all performed by contract?

Mr. Darling: Yes, all the work was done by contract,—foundation work, track work, and everything of the kind. The contractor did the switch work on a percentage basis.

Mr. Storey: In this connection I will say that most of the steam railroad companies, in the rebuilding of bridges, do not use contract work. The nature of that kind of work has seemed to necessitate the organization of their own gangs. Most of the western railroad companies have their own gangs working month after month and year after year taking down old bridges and putting in new ones.

Mr. Darling: I ought to say, in justice to contractors, that our experience was a happy one all through the work. The contractors worked under great difficulties in connection with the train service, and they did the work just as we wished to have it done. We had no trouble at all in that respect, nor on the percentage basis.

Mr. Storey: I suppose the work on the percentage basis was done at so much per pound?

Mr. Darling: Yes, you are correct.

Mr. Fruit: It might be interesting for me to state that during the work of construction the structure had to be supported for some eight months on wood blocking, on account of labor troubles.

Mr. Wm. B. Jackson, M.W.S.E.: What led to the increase in size of the bearings of the foundations?

Mr. Darling: In adding the third track it was found that there was additional weight brought on to the old foundations, so we renewed the old foundations. We took out 230 old foundations and put in new ones generally 9 ft. by 9 ft. In most cases the old foundations were renewed on the side adjacent to the new 3rd track structure.

Mr. A. Reichmann, M.W.S.E., (Chairman): There is one feature that was not brought out very clearly in the paper, and that is, that the old structure was very strongly braced all along the line from the new structure. That added quite a little to the work.

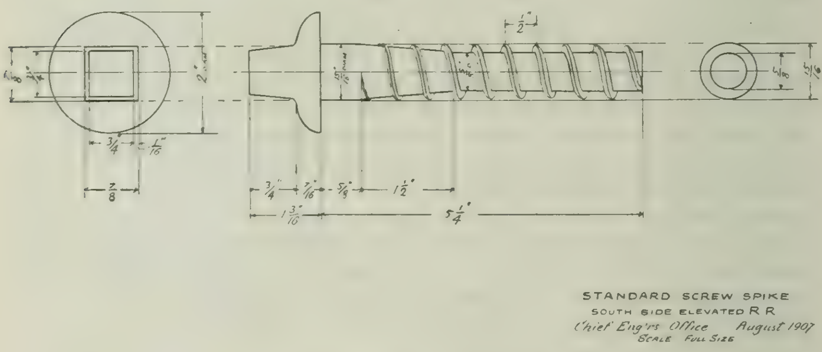
Mr. Storey: Were any special precautions taken relative to protection from danger incident to the third rail, while the work was

going on? Where there any accidents to the workmen due to coming in contact with the third rail?

Mr. Darling: No precautions were taken, and very few accidents occurred. The workmen simply looked out for themselves. Occasionally one would receive a little jolt, but I do not recall that any workman was killed from that cause.

Mr. Storey: I would point out that this is certainly a remarkable example of what can be done in electric railway construction, taking into consideration that the service was continued with very little interruption. One of the problems that presents itself is the danger to the workmen in handling track, and I can hardly conceive of a more complex case, where the men were thrown close to the third rail in all of the work they had to do, than in the work which has been shown us this evening, and a record like that deserves special attention.

Mr. Darling: It does seem remarkable that the work could be done in such close proximity to the third rail without more accidents, especially in view of the large number of trains which were in operation continuously. My experience has been, however, that where danger is ever present, one's mind is continually charged with the thought of danger, causing him to be alert all the time, and accidents are likely to be reasonably rare in such cases.



Screwspike used in new work.

Mr. Reichmann: I would ask how successful the screw spikes for securing the rails have been on this work?

Mr. Darling: It is eminently successful so far, and I see no reason why it shouldn't continue to be satisfactory in the future. However, time will tell what may develop when the track has to be renewed. I know of rails having worn out and renewals having been made, but have heard no expression of dissatisfaction or of any insurmountable difficulty in withdrawing the spike. It certainly holds the rail in place in good shape, does not split the tie, and does not destroy the wood. I think it will prove to be a very satisfactory spike.

Mr. Story: I would ask Mr. Darling what the size of the tie plate was, and also what was the style of plate?

Mr. Darling: The tie plate is flat with a little flange fitting up against one edge of the rail, anl the spike holes come diagonally on the tie. I will ask Mr. Ralls to state the size of the tie plate, as I have forgotten it.

Mr. M. S. Ralls, M.W.S.E.: The size of the tie plate is 5/8 in. in thickness, 6 in. wide and 8 in. long, with staggered spike holes, these being 15-16 in. in diameter and spaced between centers 5⅞ in. It has a shoulder or rib on one side, which sets up firmly against the flange of the track rail, but there is no rib on the bottom of the tie plate, it rests flat on the cross-tie. The spike holes are staggered, the staggered distance being 3¼ in. center to center. This is the style of tie plate used on tangent track. On curved track, where a steel guard rail is required, the tie plates vary in length, according to the radius of the curve. Those used on the curves are numbered 1, 2, 3, 4 and 5:

No. 1 is 10⅛ in. between centers of spike holes.
No. 2 is 10¼ in. between centers of spike holes.
No. 3 is 10⅜ in. between centers of spike holes.
No. 4 is 10½ in. between centers of spike holes.
No. 5 is 10⅝ in. between centers of spike holes.
No. 1 gives 1¾ in. flange way.
No. 2 gives 1⅞ in. flange way.
No. 3 gives 2 in. flange way.
No. 4 gives 2⅛ in. flange way.
No. 5 gives 2¼ in flange way.

Mr. Story: In this connection I might say that the tie plate is creating a good deal of attention, and the rib spoken of is, as a rule, put on the outside of the track.

Mr. Darling: I think it is understood that our tie plates are flat on the bottom, and that there is no rib to cut into the tie.

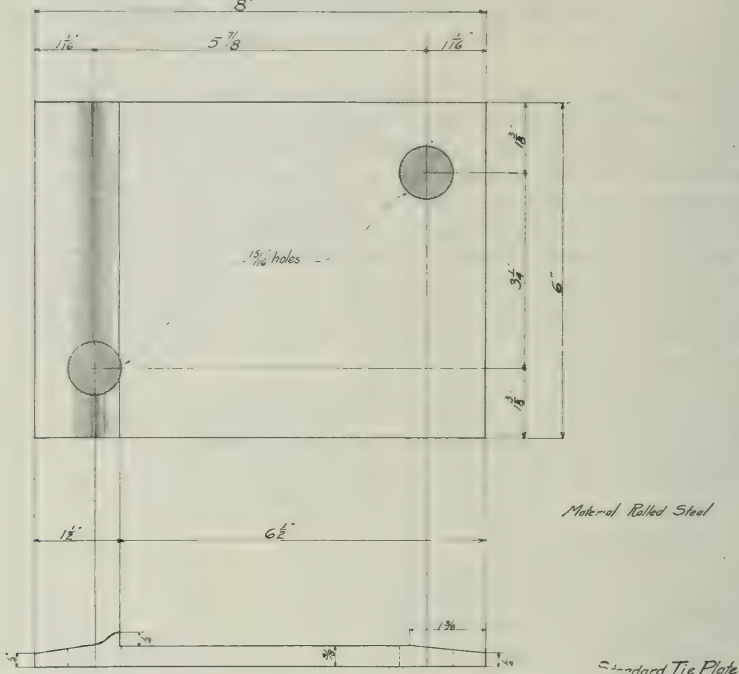
Mr. J. H. Warder, M.W.S.E.: Would not the cost of the screw spikes be about double that of the ordinary driven type?

Mr. Darling: I am not certain what they do cost, but I think they cost at least that much more than the ordinary spike. The cost of laying track is a little more with the screw spike.

A Visitor: What is the method of driving the screw spike, and about how long does it take?

Mr. M. S. Ralls: With a full force of men on double track work, 20 screw spikes per minute can be put in. The holes are bored by mechanical power, requiring two men to operate the boring machines, one engineer followed up with two men starting and setting spikes, and they followed up with two crank wrenches requiring four men to operate them, and one man to distribute the spikes. With this force of men, and everything working in good condition, 20 spikes

per minute can be put in. Compressed air was used as power for drilling the holes.



Tie plate under rails.

Mr. **E. E. R.** *Tratman,* M.W.S.E.: The wave-line grade system, with grades of 1.66 per cent. at each station, was proposed some 25 years ago for an underground railway in London (England). The line was to be operated by storage battery or compressed air locomotives. I was engaged upon the plans at one time. The line was never built, but was on the route of the present electric tube line of the Central London Ry. I would like to ask how the trains were controlled in passing over the single-track sections of the elevated railway. This is an important matter with such a frequent service of trains.

Mr. Darling: The trains are controlled by a flagman at each end on tangents and around curves one in the middle. They signal one to the other so the trains cannot come on without the consent of the men on watch.

Mr. J. G. Spielman, M.W.S.E.: In regard to the size of foundations, as I understand the construction, the new column is braced to the old structure in such a way that settlement would throw considerable stress on the bracing, and for that reason I think it is a good

thing that the foundations were made larger than usual. The old columns had settled a certain amount and would not be likely to settle any more. Naturally a new foundation would settle a little after putting it into use, and if it were made no larger than the old one, it would be fair to assume that it would settle as much as the old one, and this larger foundation would counteract the effect of settling. I understand that in your cross-girder section you put in foundations all of the same size; that would take care of that settling; otherwise your girder might be settling on one point only.

Mr. Darling: I would like to hear from someone on the subject of waving grade. I think I brought the matter out so that it was understood that the train stops at a station on a level grade, and usually it is, we will say, 40 or 50 ft. from the front end of the train to where the grade begins to drop off. It is easy enough when the train is entirely on the 1 per cent. grade, to tell how much benefit is derived by the grade as an aid to starting. The position of the train, of course, precludes any incidental benefit while the train is starting, but the advantage, due to the fall of 1 per cent. grade, does come in before the train gets its full speed. I was hoping there might be someone here who, perhaps with a due amount of thought, could give some formula that would lend itself to a solution of a general proposition of this kind.

Mr. Story: So far as steam roads are concerned, any aid in starting in getting the train up to speed is a great advantage, and a grade of that kind would be an aid. Take a train traveling at 60 miles an hour,—it begins to stop at a distance of one-half to three-quarters of a mile, and it takes it three miles to regain its regular speed. A down grade would very materially assist in getting up the speed.

A Visitor: How are the points located on the curve, in laying out the work?

Mr. Darling: They are located usually from the base line outside of the curve—from a straight line. Sometimes the situation is such that they can be located directly from the center, but the usual procedure is to lay off the base line and figure the location at the column points at right angles from the base line and figure out the distance. It is necessary sometimes to establish a sub-base line.

ELECTRIC EQUIPMENT OF SIEAM AND GASOLINE AUTOMOBILES

Mr. F. R. Babcock.

Read before the Electrical Section, May 8, 1908.

Since the earliest days of autobobile history, electricity has played an important part in the design and operation of all machines, which depend for motive power on some form of explosion or internal combustion engine. It is only within comparatively recent years, however, that it has found any purpose, save that of ignition. As might be expected, the vast increase in the application of electricity to other lines of work has stimulated its use in the automobile field until at the present day, it is taking the place of acetylene or kerosene for illumination, hand and exhaust operated horns for signalling, gears and friction devices for speed changing, and serving a host of minor purposes. It is my purpose in this paper to give a brief account of some of the various devices, combinations and arrangements, which have been used in the application of electricity to the various purposes mentioned.

The first purpose for which electricity was employed in the automobile was for ignition and this is still the most important of its applications. Two methods of igniting the charge are in general use, known respectively as the high tension or jump spark and the low tension or make and break spark. As the names imply, the former depends on a discharge of electricity at high tension between fixed electrodes inside the cylinder, while the latter uses a low tension circuit, in which is included a coil of wire having considerable self-induction, the circuit being made and broken by moving electrodes within the cylinder. These two schemes modified in detail to suit the ideas of individual designers are practically in universal use today. We will consider first, these two systems as a whole and later take up the source of electrical energy, which may be used for either one.

HIGH TENSION SYSTEM.

This consists in its elements of an induction coil for raising the voltage of a battery or generator to the potential required to jump a gap of 1-32 to 1-16 of an inch under pressure of 50 to 80 pounds per square inch. The spark plug, battery or generator, and timer complete the essential elements of the system. In detail, this simple apparatus may take one of a number of different forms, dependent upon the construction of the engine, the source of current, etc., and we will discuss briefly the principle arrangements in use.

On a single cylinder engine, the system approaches the ideal one in simplicity. As the number of cylinders is increased, the apparatus may be multiplied, making practically an individual system for each cylinder, or a single coil may be used and suitable distributing devices employed to conduct the high tension current to the proper cylinder at the proper time. Further variation may be obtained by

using either a vibrating coil which gives a succession of sparks at each contact, or a simple transformer with a single contact and a single spark explosion. In the latter case, some special type of contact maker or timer, which will cause a rapid interruption of the circuit is necessary, in order that the induced voltage may be made high enough without an undue increase in the size of the coil. The individual coil type of ignition system has had considerable popularity, owing to its simplicity and to the fact that it is easier to locate trouble in the ignition system, if a separate coil is used for each cylinder than if a single coil with a distributor is employed. It has the additional advantage that injury to one coil will not put the engine entirely out of business. Recent experiments have shown that the individual coil system has some rather important disadvantages, which will no doubt eventually limit its use in automobiles. The principle objection lies in the difficulty of maintaining uniform conditions in each circuit, the result being that the ignition does not occur at the same point in each cylinder and thus the maximum power of the engine is not obtained. In other words, the time lag of each coil circuit depends largely on the adjustment of the individual vibrators and it is difficult, if not impossible, to maintain this adjustment for any considerable period at a uniform value. Where a single coil with high tension distributor is used, the system is synchronized and this difficulty is avoided. Moreover, it is possible in the single circuit system to maintain duplicate coils and thus both avoid the possibility of failure of the apparatus and assist in separating the possible sources of defective running.

A system which offers some of the advantages of both arrangements has been recently brought out by one of the large electrical manufacturers. Its peculiarlty lies in the fact that individual coils are used with a single vibrator and condenser. The coils are placed in a fibre tube which extends over the cylinders of the engine, short high tension cables connecting one terminal of each coil to the correponding spark plug. A single vibrator with its own magnetizing coil and condenser is placed on the dash board and connected to the common terminal of the coils. The usual battery and timer complete the equipment. This scheme, while providing synchronous ignition, does away with the necessity of commutating the high tension current and as the coils may be enclosed completely and have no exposed connections or moving parts, they are not likely to give any trouble. The vibrator unit is easly duplicated and the wiring is very simple.

LOW TENSION.

The low tension or make and break system was one of the earliest in use, being employed on a Haynes-Apperson car in 1893 or 1894. It fell into apparent disfavor for a few years but up to the last year has been growing in popularity and is at present used on many of the highest priced cars. The low tension devices combine a fixed insu-

lated contact inside the cylinder and a moving contact operated by a cam or other mechanical motion. A spring device of some kind is always provided to insure firm contact between the electrodes and a quick break. The advantages of the low tension system are mainly in its simplicity, the only essential features being a source of current, a simple self induction coil and the mechanical parts on the engine. If properly made, it is synchronized, at least when new, and the spark produced is rather hotter than the high tension coil gives. It is also less subject to trouble from over lubrication and consequent fouling of the electrodes. These characteristices have given the low tension system a high reputation for reliability, especially in contrast with the earlier and less well developed high tension arrangements.

It has, however, certain features which are objectionable and as the minor troubles with the high tension system are eradicated, it seems likely that it will gradually fall into disfavor. Electrically simple, it is mechanically complicated and involves a large number of extra parts, wearing surfaces, etc., which give rise to noise, loss of compression and variation in the time of ignition. It is difficult to vary the time of ignition to suit the various running conditions and an inexperienced driver finds it much more difficult to repair and adjust. It uses considerable more energy than the high tension coils and is therefore seldom installed with battery only, a magneto or dynamo being almost essential. It is considerably more expensive in first cost. Its principle disadvantage, the necessity for a moving part inside the cylinder wall, is insuperable and it seems reasonable to believe that high tension ignition will gradually supersede it.

SOURCES OF CURRENT.

The original source of electricity for ignition was some form of primary battery. As in most other cases, the primary battery proved defective in capacity and life, and expensive to use. While in the form of a dry battery, it has retained a place in the automobile field, its use is practically confined to the smaller, cheaper cars using high tension ignition. The storage battery has been a favorite source of energy and in its improved form is a satisfactory one. It is too familiar to require extended attention here, its principle disadvantages being due to the care required in handling it. With properly constructed plates and proper attention, it is a very reliable and moderately long lived piece of apparatus. It is practically a necessity if any lighting is to be done and even where a magneto is depended upon for ignition, a storage battery is usually furnished as reserve. A form of storage battery having a semi-solid electrolyte and known as a "dry" storage battery has proven very popular. As it cannot spill or slop, it requires less attention and is considerably cleaner than the liquid electrolyte forms. It is, however, somewhat heavier for a given capacity and is less suitable in connection with a dynamo, since it will not stand excessive charging currents nor prolonged evercharging.

DYNAMOS.

These may be divided into two classes, those which try to take the place of the battery and which are therefore direct current constant voltage dynamos or magnetos and a second class which aim to provide an alternating current, a single impulse being relied on for ignition. As such machines are not self exciting, they are always of the magneto type. These mechanical devices being dependent upon the engine for power must be adapted to furnish current at widely varying speeds and considerable difficulty has been experienced in providing a direct current generator which will furnish approximately constant voltage under these conditions. The most successful attempts to do this have been along the line of friction drives in conjunction with some centrifugal governing device, which will increase or decrease the friction. The dynamo is then geared high enough so that at the lowest speed of the engine will operate at normal speed without slipping the friction drive. At all speeds above this, there is more or less slipping. The disadvantages of this arrangement or any other mechanical speed regulating device are too obvious to require comment. They are so serious as to practically prohibit the use of simple shunt wound machines without a battery. For ignition only therefore, the magneto practically controls the situation.

Magnetos for ignition may be divided broadly into two classes, rotating armature and inductor types. The first type is a development of the simple magneto with shuttle wound armature, such as is familiar to all of you in the telephone ringer. For automobile use, the magneto is made considerably larger and heavier and the armature is quite frequently mounted on ball bearings. For low tension work, a single coarse wire winding is placed on the armature. The position of the core being so adjusted with reference to the time of contact in the engine that the current is a maximum at the moment the contact is broken. The armature itself provides sufficient self induction to give a hot spark without the use of external coil. For high tension work, the same machine may be used with an external high tension coil or the high tension winding may be placed on the armature itself. In either case the contact maker is mounted on the end of the magneto shaft and if an external coil is not used, the condenser is placed inside the magnets, so that the machine is entirely self contained. For use on multi-cylinder engines a distributor must be used and this is also incorporated into the body of the magneto. The inductor type of machine is used largely for high tension work and employs a rotating cylinder separating the armature from the magnet pole pieces, the cylinder being cut away at opposite points, so that the flux through the armature is alternately short circuited and open circuited. This has the advantage that no maving wire is required, and therefore the machine is somewhat better adapted to high tension work. Recent designs in magnetos show a strong tendency to-

ward making the magneto complete in itself, the only external apparatus necessary being the wiring from the magneto to the spark plugs and a single circuit to the dashboard for stopping the engine. Thus arranged, the magneto is ideal from the car owner's standpoint as long as it operates, but a magneto which refuses to work properly for any reason is almost as hopeless a problem to the average driver as a telephone switchboard out of order would be to a high school student. The result is that the only thing an owner can do with his magneto is to take it off and send it back to the factory and if he has no other ignition system on his car this means disabling his car for an indefinite period so that the best cars now on the market furnish duplicate ignition systems, a magneto for ordinary running and a storage battery and high tension coil with distributor for emergencies.

This arrangement though beautiful in theory sacrifices the advantage of the magneto in the line of simplicity and inasmuch as the magneto is depended upon for all ordinary purposes, the storage battery used is more than likely to be in a run down condition when the emergency which requires its use arises. We will therefore take up a combination system which presents certain advantages over any arrangement now on the market so far as the writer's experience goes and which indicates what in the writer's mind is going to be the trend in automobile work. This equipment may best be described as a miniature train lighting scheme very much simplified in detail. The fundamental elements are the dynamo, which is of special design and construction, automatic devices which regulate the flow of current and a storage battery. The dynamo may be geared or belted to any moving part of the car and is of the water-proof type, made of cast steel to reduce the weight and with Hess-Bright ball bearings and very liberal commutator to insure long life and to diminish the amount of attention required. If geared to the engine, a speed variation of at least 4 to 1 may be expected and the dynamo should be capable of charging the battery at any speed throughout this range without exceeding a certain maximum current. This obviously necessitates some electrical regulating scheme, which in the case under discussion takes the form of an automatic cut-out and regulating coils on the dynamo. The cut-out not only serves the purpose of limiting the output of the generator but also automatically disconnects it, when the speed falls too low and cuts it in again as soon as the voltage of the generator exceeds that of the battery. Owing to the fact that some details of this controlling device are still in the patent office, the writer is not at liberty at this time to explain it in detail, but will say that it works very satisfactorily, the current varying from about 3 amperes at the minimum speed to 5 at the maximum.

The battery used in connection with this equipment consists of 6 cells of ignition battery in two groups, the ignition devices being connected alternately across each set by the usual two-point switch. Lights and other devices are operated across the outside terminals

of the whole battery, the dynamo being also connected across the line.

A simple ammeter on the dash serves to indicate that the apparatus is in working order and gives the driver an idea how much energy is going into the battery. As the generator supplies normally about the same amount of current that the lights demand, the battery is being charged during all day running and is only discharged at any considerable rate when the car is standing at night with all the lights on.

The result is that only sufficient battery need be carried to serve as reserve and for emergency use. As it is more likely to be overcharged and in fact must be overcharged to a certain extent to allow for unusual conditions, a special type of plate is necessary. By using a heavy, chemically formed plate and large acid capacity, a battery which will stand up under this service may be made and owing to the small ampere hour capacity demanded, the weight need not be excessive.

The type of lamp used for this equipment merits some attention, as the present acetylene searchlights throw such a volume of light that anything electrical to compete with them must be very brilliant. The source of light used is a miniature incandescent lamp having a metalized carbon filament in the form of a coil. This coil is placed in the exact focus of a spun copper reflector heavily plated with silver. This reflector is spun over a form whose surface is a true paraboloid, the result being a most efficient light giving arrangement. The filament is worked at a high temperature corresponding to an efficiency of about one watt per candle, and the lamp shown is using in the neighborhood of 24 watts. Of course the life under these conditions is very short, probably not over 50 - 100 hours continuous burning, but as the average owner does not use his headlights more than a few hours a week, his expense for renewals is not very heavy. For side and tail lamps, dome lamps, etc., miniature 12 volt lamps of 4 to 6 candle power taking 8 to 12 watts are employed.

In brief, this lighting equipment provides a generous supply of electricity at approximately constant potential with a reserve of from 4 to 6 hours, in case the dynamo is not running and demands no further attention from the driver than the ordinary care a storage battery requires. It provides a reserve battery for ignition and if vibrating coils are used, the fact that the polarity is alternately positive and negative on the vibrators diminishes very materially the wear on the contacts and also decreases materially the adjustment necessary. The dynamo is lighter, simpler and more efficient than the magneto and the nuisance of kerosene, oil, and acetylene renewals is done away with. The convenience of being able to control the lights from the seat and the diminution of fire risk are not unimportant advantages.

The number of minor devices and conveniences which are operated

electrically are legion but time will not permit to more than mention a few of them. Electrically operated horns, anunciators, telephones, wireless telegraph outfits, cigar lighters, exploring lamps, etc., are all in use on automobiles and our French friends, who seem more enterprising than we are in the matter of electrical applications, have furnished heating apparatus, curling irons, cooking devices and have even used motors for starting their engines, although I have not at present information as to where they get the energy necessary to supply such a variety of devices.

I wish in closing this paper to acknowledge the kind assistance of the Beckley-Ralston Co., who have loaned me some of the apparatus you have seen and Mr. A. S. McKee, who has given me great assistance in getting the apparatus together and who furnished the batteries and lamps for this work.

Note.—The paper was followed by an informal conversational talk, pertaining to the subject, and in explanation of apparatus exhibited.

THE CONSERVATION OF THE FORESTS AND WATER POWERS OF WISCONSIN

Mr. E. M. Griffith, State Forester.

Presented June 3, 1908.

I was pleased to hear the resolutions which were read here to-night in regard to conservation of forests. Just coming within a few days from the Conservation Conference in Washington, I, perhaps feel all the more encouraged that this country is going ahead rapidly, taking up this large question of conservation in the different lines. I have been much interested in the last year or two to see that engineers feel that that forestry is something they need to know about. In Wisconsin I am giving a course of lectures at the University on forestry, and have been pleased to find many engineers taking the forestry course. They are especially interested because of the work that the large railroad companies have been doing: planting their own timber, treating their ties to make them last longer, also the regulation of stream flow, protection of watersheds, reservoirs, etc. I am often told, in speaking, that I take it for granted that my audience know a good deal about forestry, so I am going to assume to-night that you know little or nothing about the subject and I shall in the beginning try to explain just what forestry is and what this country is doing.

Forestry is the systematic management of forests to secure successive crops of timber instead of treating the forests as the lumber companies have been doing: namely, cutting off the timber and then leaving the land to waste and revert to the state or take care of itself. Forestry has been practiced for many hundred years in Europe, especially in France and Germany. We find too that the English have done magnificent work in India. Japan also has done a great deal along the lines of forestry. In the case of Germany and France, they have carefully examined their countries to find out what portions should be devoted to agriculture and what given over to the raising of timber crops.

As we look at the reasons for forestry we find it is not simply a question of having a wood supply. England is a small country which does not practice forestry at all, but depends entirely upon her colonies for getting her timber. To see the need of forestry you only have to turn to countries like India and especially China where there has been such a tremendous destruction of the forests. In these countries the destruction of the forests has meant the destruction of the streams, the consequent loss of water power, and also water to irrigate their lands, causing famines which we so often read about. You perhaps have read how in China, a mother often questions whether she will throw her baby into the spring flood or keep it alive to face the danger of dying of starvation when the crops fail from lack of water.

Coming to this country we find, as you know, that forestry is comparatively new, as it was first taken up by the National Government in 1897 when Cleveland was in the White House. He took advantage of a very short but adequate law passed in the early days of this country by which the President was allowed to withdraw

View of one of the few fine pieces of white pine forest now remaining.

from sale, public timber lands, the idea being that the navy might need the timber in building war-ships. President Cleveland withdrew some 23,000,000 acres in the western part of this country—"in the Rockies." This action was met immediately with a storm of disapproval from practically that entire section in the west. Un-

fortunately the areas withdrawn from sale were called forest reserves and the name meant to the Westerner that it was a region to be preserved; that the trees were not to be cut or touched in any way. Their mistaken idea was, that it would probably be used for a hunting ground for the eastern sportsman. When it was found that forestry meant the systematic harvesting of the crop, and that the great areas were not to be left unproductive; that the forester went through and removed the slash, and that the forest reserves at the same time would yield wood and preserve water for the mines and also the water used in irrigating the plains for the settler, the opposition very largely died out and the work went ahead at first slowly, but straight along, proving its value and increasing by leaps and bounds, until to-day we have an area of national forests under the control of the government of 160,000,000 acres—a tremendous area, one-fifth of the total timber area in the whole United States; as big as all New England, Rhode Island, Virginia, and part of North Carolina. Still it is not as large an area as this country ought to have in order to feel safe from the timber famine which is apparently coming in the future.

You doubtless noticed in the papers that the probability is, there will be a timber famine in twenty-five to thirty years, although some of the papers have laughed at the idea, but if you will talk with well informed lumbermen they will tell you the same,—that the pine supply of the south is already waning and will be practically gone in thirty years from now; that that section, as far as we can see, in thirty years will be in the same condition as the Lake States are to-day. At the same time the great forest area on the Pacific Coast will have dropped to such a point that it will be absolutely impossible to supply the needs of this country, and then we will have come to the time when the price of timber will be very high, and we must do as France and Germany have done—adopt conservative methods of cutting. So this country will have to go through a period of 15 or 20 years of waiting until the forests which are now being preserved have grown up to such a size that they can be cut, during that time this country will suffer from a timber famine. The 160 million acres can be drawn upon very largely, of course, and the forest service is working with that idea in mind. They are not forcing the sale of timber in the least, but instead are holding back, but if the forest service wanted to do so, it could increase its revenue in this way very largely. I would like to impress upon you the fact that the forester looks upon this question of the preservation of the forests as a vitally important one to the whole country. President Roosevelt recently said that the forest problem is the greatest problem before the American people of to-day, for without the conservation of the forests there can be no irrigation, and lack of irrigation seriously affects agriculture. At the conference in Washington when they were considering the conservation of all the natural resources, the conservation of streams, water power, etc., many of the Governors of the

various states said that it all came back to the question of forestry, for without the protection of forests, navigation and irrigation would be seriously impaired. So you can see that this country is at least making a start, although it has met with bitter opposition from certain sections in the west, where the people have been in the habit of taking government land and using it for their own. That sort of thing has been going on all through the great west and naturally those people do not feel very pleased to have "Uncle Sam" stop their cutting of timber where they do not own the land.

I might say that many of the states in the east have individually taken up the matter of conservation of the forests. The western states you will see are largely provided for by the national forests. Take Idaho with 20,000,000 acres of national forests. Naturally she is not going to establish any reserves of her own, but the eastern states have been obliged to create many of their forest reserves. New York state takes the lead and has 1,500,000 acres in the Adirondacks and Catskills. They were acquired in the first place to protect the head waters of the Hudson River. The demand came from the owners of the steamboat lines on the Hudson River, as the water was getting too low for navigation. Next in order is Pennsylvania with 700,000 acres, and that is small in comparison to what Pennsylvania ought to have. I am glad to say that Wisconsin ranks third with an area of forest reserves of 300,000 acres, and this brings me to what I have to say in regard to the work that is being done in my own state.

As your President has said, the forestry work in Wisconsin is only about four years old. The law was passed in 1903 and the opposition of the lumber companies is just dying out; that is the trouble, they do not call in the forester until the patient is very, very ill. The question often asked is how much land are we planting—as though that was all the forester had to do. That is not the true function of the forester. His real work is to take a timber tract and handle it so that it will always produce successive crops of timber. The forests of Wisconsin had gotten into very bad condition before the lumbermen were willing to have the matter taken in charge. They did not want to have anybody interfering with their business in the northern part of the state. In recent years especially during the term of President Roosevelt the interest taken in forestry has been enormous, and Wisconsin now has by far the best forest laws. In the first place our Board is composed of five men not active in politics, so that the matter is absolutely free from political influence. The chairman of the Board, Mr. Van Hise, is President of the University of Wisconsin. Two other members of the Board are also connected with that University. Consequently that will block any adverse action by the Legislature in the future. All lands owned by the state in the northern part of Wisconsin are now included in the forest reserves and the Board is authorized to sell the scattering and agricultural lands and to purchase with the proceeds of such

sales, which are placed in a forest reserve fund, other lands which are deemed suitable as additions to the forest reserves. The proceeds of the sale of all timber, in fact even grass and cranberries, go into the forest reserve fund, and thus we can continue to buy more land just where it will do the most good. This is the same plan which has built up the great work of the Reclamation Service and is an extremely important feature of our forestry law, as it largely obviates the necessity of asking for appropriations and will in time place the department on a self-supporting basis.

The United States has given 20,000 acres to Wisconsin as an addition to the forest reserves, and in the same way the scattered and agricultural lands in this grant may be sold with the consent of the Secretary of the Interior, and the proceeds used in reforesting the burnt and denuded lands of the forest reserve. Another provision of the law allows us to purchase lands which are forfeited to the counties for non-payment of taxes. As you probably know, the old custom was for the lumbermen to go in and strip the land of the timber, leaving a barren tract, let the lands revert to the county, and then the county in turn would sell it to anybody who would pay from 20 to 25 cents an acre for it. In that way hundreds of thousands of acres fell into the hands of speculators, but under the present law the forestry Board is given the first chance to purchase. At the last session of the Legislature another section was added to the law, providing that a person who plants forty acres with forest trees shall be exempt from all taxes on the land for a period of thirty years. This law is but the entering wedge and we hope in time to exempt all growing timber from taxation, provided it is listed with the state and managed according to forestry regulations. You will find that our forests are being taxed to death, that the owner is often compelled to destroy his forests or be financially destroyed by the assessor, particularly if he be a non-resident owner. Forests are crops, and in common justice they should be taxed as such. Our crude system for the taxation of timber lands kills the goose that lays the golden egg, for not only does it put a premium on forest destruction, but it as surely destroys the industries dependent upon timber for raw material. Space prevents my going into this most important matter more in detail, but I think that when this question of taxation has been decided justly and fairly the states must step in and in return for making forestry a practical business proposition for the individual, say to him just how and in what manner he may cut this timber. You have doubtless noticed in the papers that the Supreme Court of Maine is of the opinion that the Legislature has a perfect right to do this under the general police powers of the state and for the protection of all its citizens.

As you will realize, another very important question in connection with forestry is the prevention of forest fires, for unless we can prevent fires, forestry will not be practicable. Probably not over 40% of the magnificent forests which only a few years ago covered

Northern Wisconsin ever were utilized, for the rest went up in smoke and the carelessness and indifference of our people to the appalling loss from forest fires is a dark blot on our civilization. In order to extinguish forest fires and to prevent them as much as possible, we have over three hundred fire wardens in the northern part of the state, and now the railroads and large lumber companies are co-

After the "Lumber Jacks" comes the fire and lays the land desolate.

operating with us to protect this region. Our forest reserves of 300,000 acres we hope to increase within a few years to from 2,500,000 to 3,000,000 acres, and probably nearly all of this must be acquired by purchase.

The three main objects of forestry in Wisconsin are as follows: (1) To conserve by wise use the timber on the headwaters of the important rivers, thus protecting and improving the navigability of the streams and the valuable water powers. (2) To supply from the forest reserves a considerable part of the timber needed by the wood using industries of the state. (3) To protect the beautiful lake region of Northern Wisconsin as a great resort, not only for the people of Wisconsin, but the whole Mississippi valley. The first object, as it includes the protection of the great river systems of our state, is by far the most important. We have no coal deposits in Wisconsin and in future we must look to the water powers for the energy to be used in running factories, lighting our cities, etc. In two counties, Vilas and Oneida, there are over 1,200 lakes, probably more than in any equal area in the United States. In this region most of the important rivers of the state rise, and we are working to

concentrate the forest reserves here so that the stream flow may be held even and constant. In this connection I will explain the reservoir bill, which was passed at the last session of our Legislature, for as far as I know nothing similar has been done in any other state and I think it will be of interest to a society of engineers. There is a provision in the Constitution of Wisconsin that the state cannot enter into internal improvements, and, therefore, the state cannot build reservoirs at the headwaters of our rivers to regulate the flow, with state funds. But in 1907 the Wisconsin Valley Improvement Company was given a charter by the state to establish reservoirs on the headwaters of the Wisconsin river, under the direct supervision and control of the State Board of Forestry, and the Public Utilities Commission. The Forestry Board has control of the field work of the company, as they must approve the building of all dams, including the height, amount of land to be overflowed, and also the time and manner in which the water shall be drawn off. Here the Public Utilities Commission steps in and fixes the tolls which the company may charge to the users of water power, which the law specifies shall not be more than sufficient to pay 6% dividends on the cash capital actually paid in. The bill further provides that any new reservoir shall not be built out of the net earnings but from new capital stock, and that as new water powers are developed there shall be issued to the owners their pro-rata amount of stock so that all will have an interest in the work. At present the reservoirs are storing about 2,600,000 cubic feet of water and this will be increased about 1,000,000 cubic feet this year. During the summer months the law provides that the water in the lakes shall not be drawn down so as to lessen the value of the lakes for resort purposes, but during the winter months, of course, there is no objection to the water being drawn very low, for the lakes will then be filled up with the spring freshets and thus greatly lessen the damage by floods on the lower Wisconsin. The law has been in effect only since 1907, but the reservoirs which have already been established have been sufficient to increase the horse power on the Wisconsin river over 20%, and from the reservoirs which can be built we expect to more than treble that. The theoretical amount of horse power upon the Wisconsin river is 151,000, but the actual horse power used is only 72,000, so that we have developed only half the horse power on the Wisconsin; and upon most of our rivers the proportion is even less. The forest reserves and the reservoirs supplement each other in making the stream flow steady and constant, and certainly engineers will appreciate how enormously this will add to the value of our water powers in Wisconsin. There is hearty and complete co-operation between the state and the reservoir company and personally I feel that even if the state had the power to build the reservoirs, it would be better to have the men who are directly interested to do so, and that the very broad control of the work which the state now has, is sufficient to safe-guard the interests of all. As I have stated, I do not know of

any similar legislation in this country and I feel that it is but the beginning of the great work of protecting our water powers. It is hoped that in time the state will own a large enough area of timberland within its reserves to assure many working industries a permanent supply of raw material.

When the forests are removed on the headwaters of the streams—then floods follow.

The third object of the forest reserves, to provide a great and attractive resort, is also important as it will mean a large and increasing revenue to the people of that section. The tourist business in the Adirondack Mountains of New York amounts to over $10,000,000 a year, and our beautiful lake region in Northern Wisconsin already draws thousands of visitors, many of whom come from as far south as New Orleans.

In conclusion I wish to say that Wisconsin has lost enormously by her failure to create a department of forestry many years ago, as then the state lands would have been managed under forestry regulations instead of being sold as they were for a song and then stripped of their timber and left nearly a barren waste. The state can never fully recover this great loss, but a start has been made that will protect our great rivers and give us a supply of timber in the future.

DISCUSSION.

President Loweth: The speaker was much impressed with the author's remarks about the determined and intelligent effort being made in many countries, especially in China, not only to conserve the forests, but to grow new ones.

Surely this country ought not to show less foresight and consideration for its future welfare.

Mr. E. N. Layfield, M.W.S.E.: I think Mr. Griffith has made it very clear to us why we should preserve our forests. I would ask him to give us the benefit of his ideas on the question of the second growth timber. We ordinarily regard second growth timber as very poor stuff, and I haven't a very clear idea of what this new timber is going to be. This new cultivated second growth timber would no doubt be entirely different from our ordinary second growth, and I think it would interest us to have Mr. Griffith go into this phase of the matter.

Mr. Griffith: In answer to that question I will say that the only reason second growth timber has a bad name at present, is because no timber has been grown systematically in this country. The first growth timber, we had, as you know, is a case of the "survival of the fittest." The virgin trees which had stood in the forests for many many years had grown close together, and consequently without limbs and without knots. The lumberman, when he gets through cutting, leaves an enormous amount of slash on the ground and fires burn through it. The young growth starts up, but not in any order, and the natural inclination is, as it comes up to throw out limbs, and these limbs often extend down to the ground. However, when the trees are grown close together they cannot throw out such limbs and the result is a much finer timber than has ever been grown in the world. The finest timber I think is found in Germany. That kind of timber, of course, has got to come slowly in this country.

The railroad companies are becoming alarmed as to where their ties are to come from. They are already paying high prices for timber. One fortunate thing about this matter is, however, that it has been found by creosoting ties with a solution, the poorer the timber for manufacturing purposes, the more porous it is, the better it is for the creosoting treatment and also for the duration of the ties. It has been found that certain kinds of pines to be found in Northern Wisconsin made into ties and so treated, will last about as long as 60 or 70c white oak ties. Those pine trees naturally take the treatment more thoroughly and it is easier to distribute the solution all through the wood, whereas in the hard white oak ties it is difficult to secure perfect impregnation. Consequently the demand for the second growth timber is going to be enormous from the railroad companies.

Mr. W. L. Abbott, M.W.S.E.: About thirty years ago a law was passed, enabling settlers to take up Government land and get a title to the same by means of tree claims. That is, if the settler would plant trees upon a portion of the land so taken up, he would, in course of time, acquire a title to the whole tract of land. I am not positive as to the exact provisions of this law but as I now recollect it, if the settler planted trees on forty acres of land, he might acquire a title

to eighty acres, or possibly double that amount. This scheme was very popular with the settlers so long as it lasted, for it enabled them to get a good deal more land than they could otherwise have preempted and they found that as soon as they had acquired a title to the land under a tree claim, it was not a difficult thing to cut down those trees, grub out the stumps, and plow the whole land. In other words, the land was considered too valuable to be used for timber purposes.

Mr. Griffith referred to regulations of the Wisconsin Forest Service which grant the privilege of acquiring cut-over land and selling off the agricultural land. I am interested to know how he distinguishes between agricultural land and forest land, and also at what value it is considered not profitable to use the land for forest rather than agricultural purposes.

Cutover lands, restocking with white and Norway pine.

Mr. Griffith: In answer to Mr. Abbott's first question I will say that in some cases it is a close question as to what is agricultural land and what is more suitable for forest growth. One of the members of our Board is connected with the State Agricultural Department, and he was appointed with the idea that he could assist us in making the distinction, but so far we have had little difficulty in that direction. In Oneida and Vilas counties there are great pineries, and where there are many pine trees one can be very sure of a sandy

soil. In that region the soil is white sand, and being so far north it is not considered good agricultural land. Sometimes there is a clay mixed in it where a man can farm, but just how far they can go by making that soil productive, we do not know, but so far it is pretty safe to say that most of that land is more valuable for timber than for crops.

Referring to Mr. Abbott's second question, as to what value it is considered not profitable to use the land for forest rather than agricultural purposes, I will say that we have studied that matter a good deal and have finally concluded that no land of a value to exceed $10.00 per acre should be planted with trees. Up in our farming country, however, where a good deal of the land is worth $200.00 an acre, many farmers want to plant a good deal of the land with trees. They figure out that in the future they will get more for their land with trees on it than without them. They think it is better for them to have a little wood lot by which they can be independent. But, as I said above, we think a man should not plant trees on land worth more than $10.00 an acre.

Mr. Abbott: How long does it take to raise a marketable crop of pine?

Mr. Griffith: The age limit is decreasing as the demand increases. It usually takes about thirty years. We get about 6-inch sticks in thirty years.

Mr. Layfield: What is the shortest period it will take to grow a full size large tree?

Mr. Griffith: It takes 150 years for that old pine that is being cut in Northern Wisconsin. That fine class of timber cannot be produced in a hurry. President Roosevelt has very well said that the length of the timber famine, when it comes, will be marked by the slow growth of the trees themselves.

Mr. Layfield: How long have those trees in Germany been growing? When was this system started in Germany?

Mr. Griffith: It has been in operation now nearly 300 years. The forests are sometimes run on a 300 years rotation.

Mr. Abbott: How many feet of lumber would they get per year?

Mr. Griffith: They get an enormous amount, and much heavier than anything we know of for the same species. It often runs from 70,000 to 100,000 feet per acre, and the trees are often 90 to 100 feet to the first limb.

Mr. Layfield: That 300 year period could be much reduced, could it not?

Mr. Griffith: Yes, I presume some reduction in time could be made.

A Visitor: What is the situation in Michigan?

Mr. Griffith: Michigan has been in a peculiar situation, and politics has played an important part. The northern lands were sold to speculators. The speculators would take an acre and cut it up into 15 or 20 lots and sell these lots at $1.00 apiece. Thousands of those

lots have been bought and the owner would pay \$1.00 apiece. Then the land would lapse to the state, requiring more work in the land office, more clerical labor, etc., etc., until in Saginaw last year, at the forestry conference, it was shown that Michigan has spent an enormous sum in selling their state lands, and has today several thousand acres more than she started with. At the last session of the legislature a Board of nine members were appointed who are studying the whole question of Michigan's land policy, and I imagine when Michigan starts, she will start with a bound. She has now six million acres of land which have reverted to the state for non-payment of taxes.

Mr. Layfield: In reforesting, is it the idea to always reforest with the same species of trees as originally grew there?

Mr. Griffith: They must select a species best suited for that locality and soil.

Mr. Layfield: I suppose you might put some timber in a certain locality more valuable than that which grew there originally, and which had never been grown in that neighborhood before?

Mr. Griffith: In Wisconsin we are going to grow white spruce where the land never produced that kind of timber before.

Mr. W. B. Jackson, M.W.S.E.: If I understood correctly, Mr. Griffith stated that the forest work in Northern Wisconsin had already increased the actual water power of the river about 20 per cent.; in other words, one-fifth. That means a tremendous gain for Wisconsin and at once shows, to a certain extent, the great value of the forest development in the state. I would ask Mr. Griffith if he has figured upon what will be the ultimate effect on the Wisconsin river when everything they can do in the line of forest preservation and reservoirs is completed?

I was also much interested in the statements regarding the reservoirs being built in the northern part of the state, which I presume at the present time are, to a large degree, embryonic. I believe it was stated that the present capacity is 2,600,000,000 cubic feet of water at the present time. I would be interested to know what is figured the capacity of the reservoirs at the head of the Wisconsin river is likely to be when all practicable reservoir sites have been developed?

This whole subject is one of such immediate interest to the engineers and has been presented so admirably by Mr. Griffith, that I feel it must have been through a sense of modesty that he said he wondered why the engineers were so much interested in forestry.

Mr. Griffith: In regard to the ultimate effect on the Wisconsin river, we have not been able to figure on that at all. When I say "we," I mean the State Board of Forestry. What we have done, is to establish dams upon nine different lakes at the head waters of the Wisconsin river. These nine lakes now give us a storage capacity of 2,900,000,000 cubic feet, and we hope to increase that this year by 1,000,000,000 cubic feet.

In regard to the increase in water power of the river of 20 per cent., my authority for that statement is the hydraulic engineer, and the men who paid the tolls have satisfied themselves it is correct. As far as we can see from the reservoirs which we will get—and in some of those reservoirs it is going to be expensive to acquire all the land—but when we get those which we already know of, we expect to increase each horse power at least 60 per cent. on the Wisconsin river, and that does mean a great deal to the state of Wisconsin. That is perhaps not so important as to insure to the whole state of Wisconsin that those water powers are going to be permanent.

President Loweth: The author's reference to the storage reservoirs at the headwaters of the Wisconsin river reminds the speaker of the several similar reservoirs in the headwaters of the Mississippi river. These were built by the Federal Government, about twenty-five years ago, as a part of a plan for the improvement of the Upper Mississippi river for purposes of navigation. They were made by damming the outlets of several large lakes at the headwaters of the river in Northern Minnesota, and were intended to retain a large portion of the flood waters, and by releasing these during the seasons of ordinary low flow to materially increase the depth of low water in the navigable portions of the upper river. The speaker thinks these works were built for no other purpose than for the improvement of navigation, and, if his memory is correct, that they have not proven as efficient for the purpose intended as was anticipated, and that other means, principally wing dams, contributed more to the value of the river for commerce than did these reservoirs.

The reservoirs, have, however, been of much benefit in other ways; doubtless in reducing the extreme height of floods, in making a higher average of summer flow, thus aiding in the driving of logs to the numerous mills lower down the river, and in increasing the minimum power in the ten or a dozen large waterpower developments in and above Minneapolis. Recently an effort was made by interests claiming to be adversely affected by the great extent of low lands flooded and otherwise rendered valueless by these reservoirs, to have them abandoned. This move was strongly opposed by various interests adjoining the river below the reservoirs, especially by the several large water power interests, and after an investigation by a commission of United States Army Engineers, appointed for the purpose, the abandonment of the reservoirs was adversely reported upon; largely, if the speaker's memory is correct, on account of their general benefit.

Any one acquainted with the lumber industries of Northern Michigan, Wisconsin and Minnesota, for only so short a period as twenty years past, on looking over the situation today, must keenly realize how great has been the destruction of our forests.

The Chicago, Milwaukee & St. Paul Railway, with which the speaker is connected, taps those sections of these states, which twenty to twenty-five years ago were covered with virgin forests of

the finest timber grown, and was able to draw all its supplies for bridge, building and car construction from mills on or near its own lines; but today, with a consumption of perhaps 70,000,000 feet board measure of sawed lumber, not more than about 20 to 25 per cent. can be obtained from these same sections, and that of not nearly as good quality; the balance must be brought from the South and the Pacific Coast, the latter source more and more predominating.

A. Bement, M.W.S.E.: (By letter.) Not only is it fortunate that this society of engineers has had this vital subject of Forestry so well presented before it, but the occasion is most significant as affecting the welfare of the community in general. The impetus given this matter by President Roosevelt, and the participation in its consideration by engineering societies as well as other bodies which come more directly in contact with the industries of the country, insures that the people in general will realize the advantage and necessity of proper cultivation and preservation of forests. In this connection the fact that the work of the American Forestry Association is bearing such excellent fruit, should not be overlooked. To the average citizen, the most important benefit to be derived from forestry is usually considered that of timber supply, although I am not sure but this is the one of least importance, because reinforced concrete and metal have been substituted for wood, even to the extent of construction of roofs and furniture. Thus we can conceive of the possibility of doing entirely without timber, because our natural mineral reserves are so much greater than any amount of timber of which we can imagine as being available. To my mind, the most important necessity for forestry maintenance and development, is that of agriculture and the preservation of rivers and streams. It is only necessary to take into consideration the author's excellent lantern slide views showing conditions in China, brought about by the almost total extinction of forests, to prove that it would not take very long after their disappearance for a rich agricultural country to become practically a desert, as has actually transpired in portions of China. Thus while we might get along without timber, we could not exist without food.

As affecting the rivers, relative to navigation, it is not necessary, although desirable, that we avail ourselves of the opportunity afforded by them for transport, because there is another satisfactory method, than by railways. Regarding the matter of water power however, if the stream supply fails the power is lost, while with transportation, in case of stream failure we resort to the railroad, and I believe that this danger is seldom taken into consideration in connection with development of water power projects.

Mr. E. E. R. Tratman, M.W.S.E.: (By letter.) One of the important points suggested by Mr. Griffith is that of the reliability of water supply for power purposes. During the past few years there has been a remarkable development in the utilisation of water power, and it is most important that the estimated capacity should be maintained. In many cases, this is hardly practicable except by methods

of storing or holding back the flood waters. This has some bearing upon the reputation of the engineers of the plants. In one particular case, an engineer was severely criticised because a plant did not have sufficient water supply to develop its rated capacity at all times. It seems not unlikely that a study of the run-off data and other records may have warranted the assumption of a steady supply, but that deforestation on the drainage area may have so changed the conditions as to produce alternations of flood and low water in the stream. Under such conditions additional works may be necessary, in the form of reservoirs to hold back the flood waters for use during low-water periods.

SPECIAL CONCRETE STRUCTURES IN THE HUDSON RIVER TUNNELS

W. M. TORRANCE, M.W.S.E.

Read April 1, 1908.

A very important part of the final subway railroad system of the Metropolitan district of New York is that now under construction by the Hudson Companies.

A plan of this system as at present authorized and under way is shown in Fig. 1. The portion from the Hoboken terminal to Nineteenth street and Sixth avenue, New York City, has been completed and was opened with formal ceremonies, February 25th, of the present year. As shown by this drawing, there are two sets of double tunnels under the river, which are connected on the New Jersey side. The upper set reaches from the foot of Fifteenth street, Jersey City, to the foot of Morton street, New York City and thence up Christopher street and Sixth avenue to stations corresponding with, and almost directly underneath, those of the Sixth avenue and Ninth avenue Manhattan elevated railroads. A branch extends to Astor Place and has a passage-way connection with the Astor Place station of the New York Subway. The lower set of tunnels makes a loop on the New York side at Church street between Cortlandt and Fulton streets, where twin terminal buildings extend from one to two stories below the subway tunnel track level (80 or more feet below the street) to twenty-two stories above the street.

This tunnel system was started in 1874, a shaft being sunk at the foot of Fifteenth street, Jersey City, in that year. Tunnel construction from this shaft eastward and from a shaft at the foot of Morton street, New York City, westward was carried on during the years 1881 and 1883, when cessation of work was caused by a lack of funds. The work built at that time had brick walls about thirty inches thick with a thin iron casing, and was constructed by the "pilot tunnel" method—a 6 foot pilot being used. A total of about 2,000 feet of the northern tunnel and 600 feet of the southern tunnel was finished at that time from the New Jersey shaft, only a small amount of work having been done from the New York end.

In 1890 the construction work was continued by an English company, with S. Pearson & Sons, contractors; this time by use of the hydraulic power shield method, using cast iron rings. This was the first large tunnel on which this method of construction was adopted. In 1891 the work was again abandoned on account of lack of funds, after the northern tunnel had been extended 1,700 feet further toward New York.

In 1900, Mr. Charles M. Jacobs, an English engineer of wide experience in difficult tunnel work, made a careful survey and detail examination of the work, and in 1902, the present company (Hudson

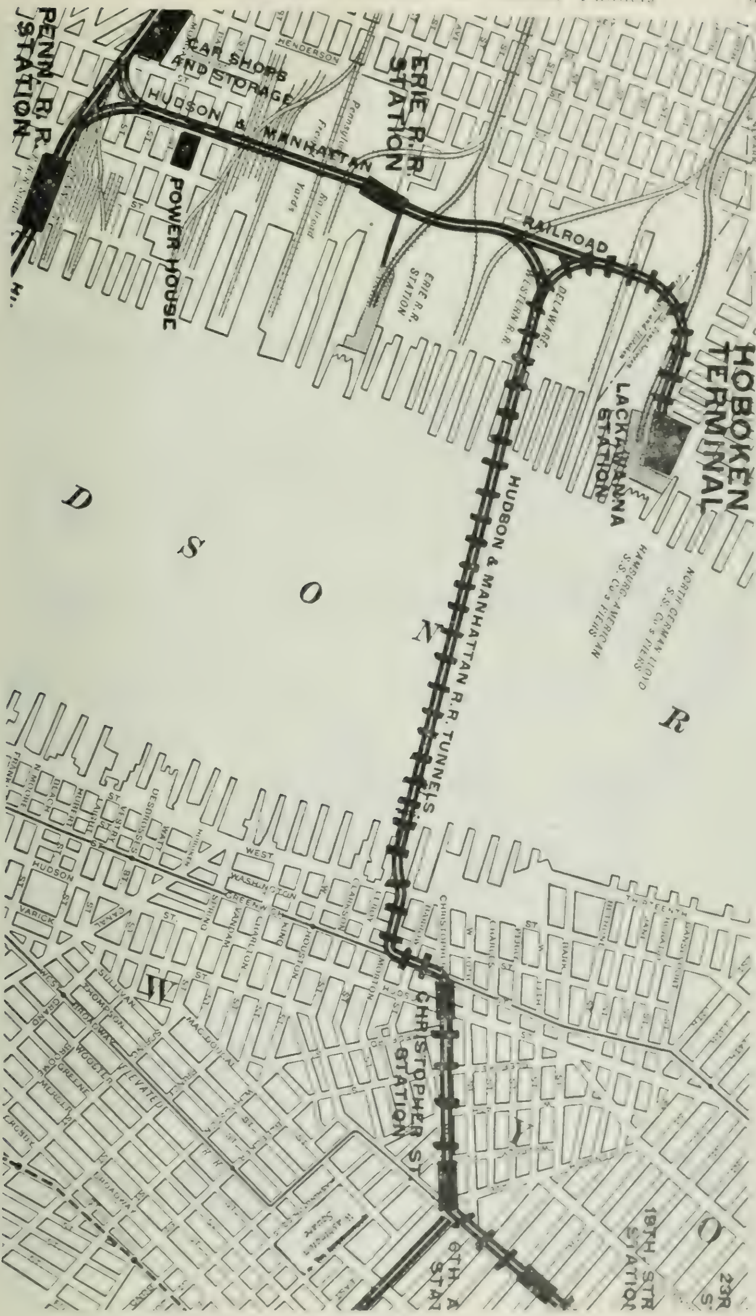

PENN. R.R. STATION
CAR SHOPS AND STORAGE
HUDSON & MANHATTAN
POWER HOUSE
ERIE R.R. STATION
RAILROAD
DELAWARE
HOBOKEN TERMINAL
LACKAWANNA STATION
HUDSON & MANHATTAN R.R. TUNNELS
NORTH GERMAN LLOYD S.S. CO.'S PIERS
HAMBURG-AMERICAN S.S. CO.'S PIERS
CHRISTOPHER ST. STATION
19TH. STR. STATION

Fig. 1.

Companies), with Mr. Jacobs as Chief Engineer, began operations. They found the shield, abandoned at the heading in 1891, in good condition and completed the tunnel to Morton street, New York, on March 11, 1904, using the old shield.

On September 22, 1905, the present company also completed the southern tunnel, this bore being from end to end a circular, shield-driven, cast iron ring tunnel; the 600 feet of brick tunnel built in 1881-1883 having been abandoned.

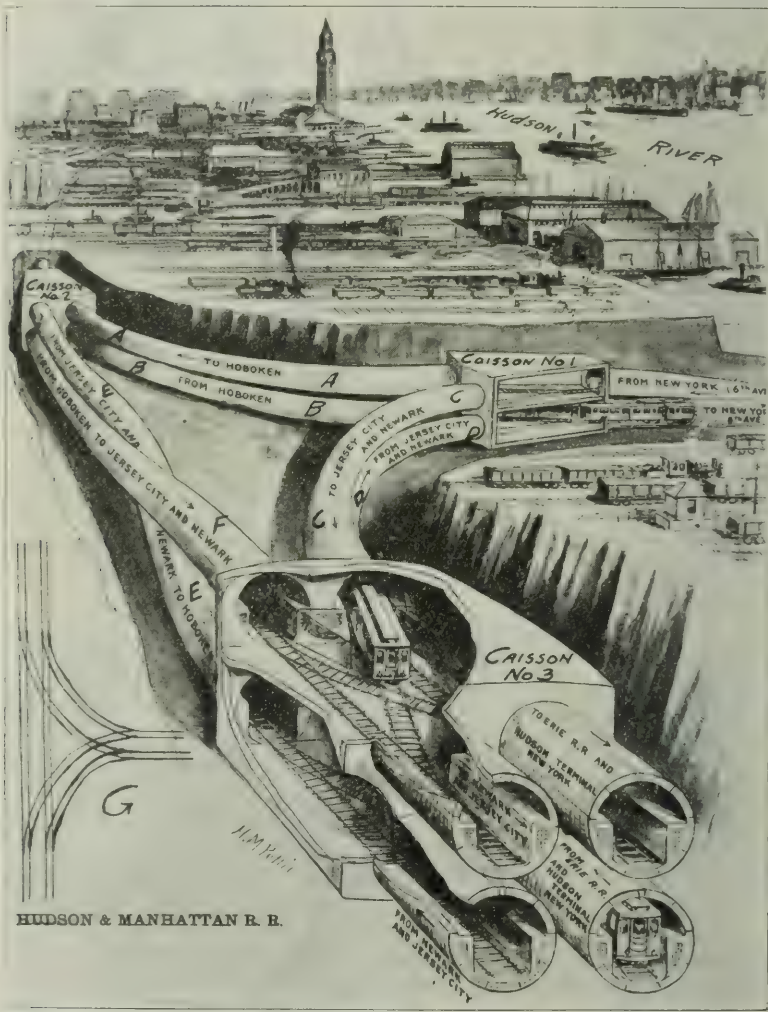


Fig. 2.

Fig. 2, is from a free hand sketch showing in perspective a portion of the tunnel system on the New Jersey side. The tunnel marked "A" contains the west-bound track to Hoboken, and "B" the east-bound track from Hoboken. The tunnels marked "C" and "D," "E" and "F" will contain tracks leading respectively from and towards Jersey City. In order to obtain the proper directions it was necessary to cross the tunnels "E" and "F" vertically.

It was obvious to the engineers that it would not be economical to construct the tunnels at the turnouts by means of a shield. It was necessary to have a section of tunnel which would enlarge from the ordinary circular tunnel at one end to a sufficient width at the other for two such tunnels to be driven forth. Many studies were made to determine the best means of accomplishing this end, the final decision being to construct such a piece of tunnel on the surface of the ground and sink it by means of a pneumatic caisson excavation.

In order to avoid grade crossings in this double tracked wye such as would occur if the tracks were made parallel to each other at grade, (see the sketch "G" of an ordinary double track wye. Fig. 2), the grades of the two tunnels were made at different levels, and in order to save cost in the construction of the caissons, they were built double decked, the enlarging tunnel for one system of tracks being directly over that for the other, thus making the floor of the one the roof of the other. Otherwise it would have been necessary to have separate caissons for each level.

Structural steel caissons were designed for this purpose, but found impracticable because of cost and the length of time necessary for fabrication and erection. Further studies were made along two lines: First, to see if the design could not be simplified by the introduction of knee braces and a reduction in depth of girder by allowing at least a portion of the compression stresses to be assumed by the concrete filling; and second, by constructing the caisson wholly of reinforced concrete with practically all the compression stresses taken by the concrete. The latter plan was adopted, the principal reasons for the decision being:

First: The saving of time due to the fact that concrete materials and reinforcing iron could be obtained promptly, thus allowing the work to start at once.

Second: Because it was found that the amount of concrete required in the structural steel caisson to overcome the buoyancy due to the use of compressed air and to skin friction was fully as great as the total amount necessary in the reinforced concrete design.

Third: A considerable saving in cost, estimated at $100,000 per caisson, chiefly because of the saving in steel. In Fig. 3, is shown a plan of Caisson No. 1, somewhat in detail. The calculation showed a necessary thickness of walls of three feet, but three feet more was added for the electrical conduits. This extra thickness was added at the outset in the middle portion in order to increase the weight.

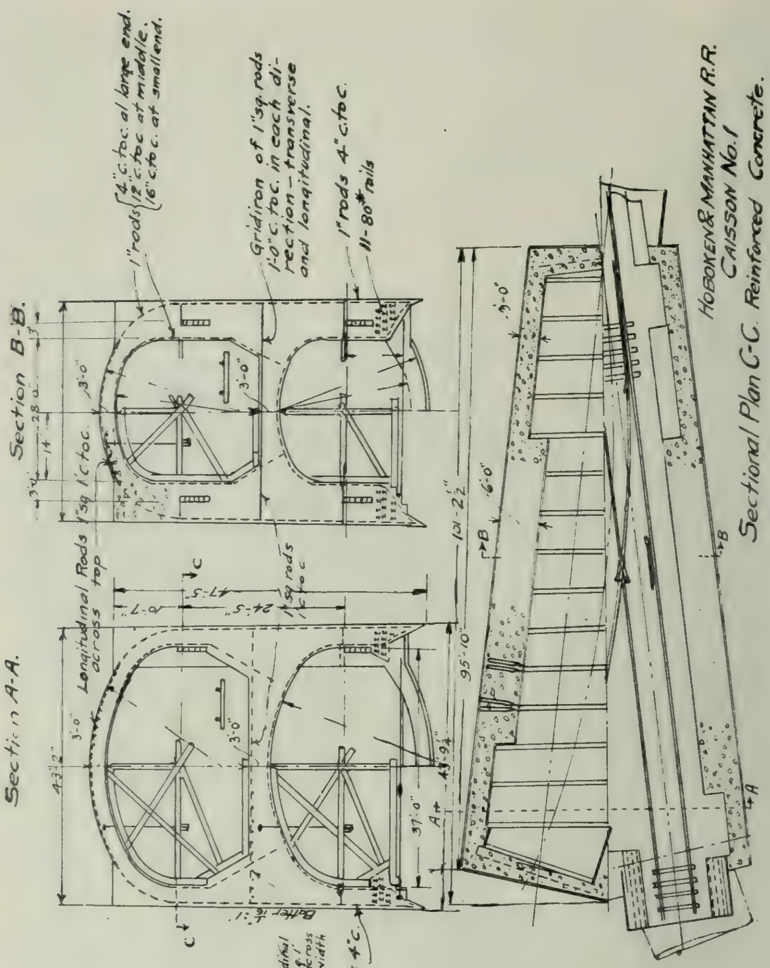


Fig. 3.

The method of construction adopted was (1) to build the lower portion and (2) sink it until the roof (floor of the second deck) would be at or near the surface of the ground. Then (3) to build the second deck on top of the first, after which (4) sinking should continue to the depth required by grade of tracks and (5) the invert of concrete placed. If the whole structure had been built on the surface before sinking started, the weight would have been too great to allow proper control of the sinking, and the construction of so high a structure would have been much more expensive.

Notes on Design.

The design was required to satisfy every possible condition of stress under widely varying conditions. In the first place, the lower deck had to be designed to resist the spreading, due to the inclined bottoms of the walls, and also to the pressure from the compressed air in the chamber. Rods $1\frac{1}{2}$ in. diam. with ends upset to 2 in. and with turn-buckles, were bedded in the concrete and extended across the structure, tying the bottom of the caisson together; also, the 12 by 14 in. timbers which extended across the bottom were anchored into the concrete by means of several rods in each. At the level of the springing line of the arch, the horizontal timbers of the forms were anchored to take tension as well as compression. The steel cutting edge, shown in Fig. 4, was designed with very strong corners, and was anchored firmly to the concrete by cross straps and by rods which extended up the inside of the cutting edge and wall.

Fig. 4.

Secondly, the side walls of the lower deck had to be designed to resist the outside thrust due to hydraulic or wet earth pressure, and as the bottom was open inside the cutting edge, these forces required the 12 by 14 in. timbers to act as struts all the way down, and also required strong reinforcement in the outside portion of the wall. Square 1 in. rods of steel, were placed vertically, 4 in. c. to c. to take the tension due to the cantilever action of these forces.

Thirdly, it was necessary to design this lower portion as a longitudinal girder in order to allow for any possible uneven bearing that might occur in the sinking. For this purpose, besides the steel of the cutting edge, railroad rails were used longitudinally, with laps of

about 10 ft. and 3/4 in. end anchors, and also longitudinal 1 in. square rods placed near the surface of the concrete in the top.

Fourthly, the upper cover of this deck had to be designed to take compressed air pressure from either above or below, the other side being normal; to take the horizontal thrust due to the earth and hydraulic pressure on the sides of the structure and to take the weight of ballast, tracks and train in the upper deck.

Fifthly, the ends had to be designed so that they could be easily and expeditiously removed, and at the same time so as to successfully resist the air pressure from within and the earth pressure from without. To accomplish these purposes best it was decided to use three feet of concrete bounded by larger cast iron rings, large enough to allow the free passage of the shield later after the concrete had been removed.

The upper deck was not designed for quite such rigid conditions but was of course designed to carry the final static load of earth above.

As the chance for uneven bearing of the cutting edge might increase as the depth increased, the completed caisson was made still stronger as a girder by adding still more longitudinal reinforcement near the top.

The unit stresses allowed in this design were 25,000 lbs. per sq. in. of tension or compression in the steel, and 600 lbs. per sq. in. compression in the concrete.

Fig. 5.

In Fig. 5 are shown some of the details of the design which amplify the drawings, Figs. 3 and 4. The forms were left in place until the final position was reached. There is also shown the longitudinal angles, which served the double purpose of holding the outside form lagging and of spacing, by holes through the horizontal leg, the vertical reinforcing rods at the outside of the concrete; these angles also served as additional longitudinal reinforcement.

Equipment—Notes on Construction.

A stock pile of stone and sand was made between the railroad tracks facing the large end of the caisson, and a stiff leg derrick shown in Fig. 6 delivered the material to a No. 4 Smith mixer set up

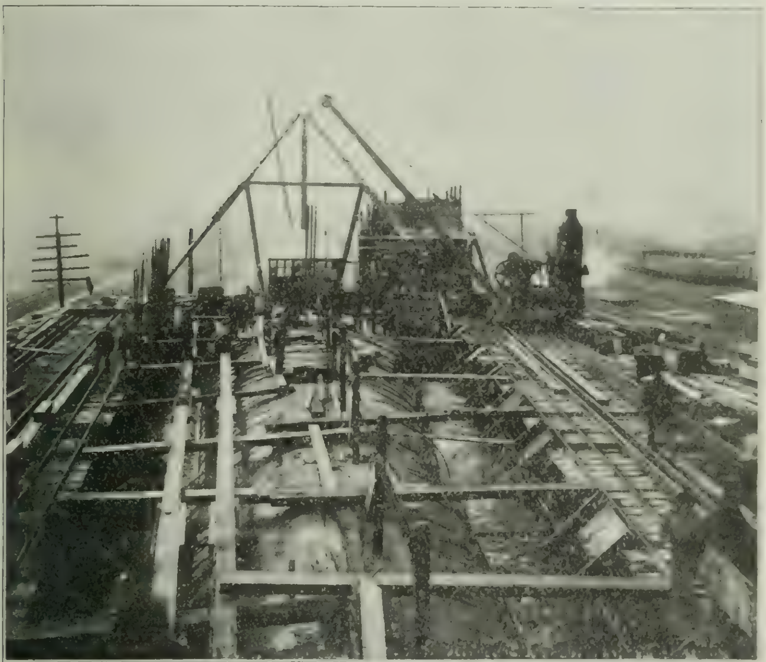


Fig. 6.

under one of the stiff legs. The measuring hopper, divided vertically, held 20 cu. ft. of stone on one side and 10 cu. ft. of sand on the other. Five bags of cement completed the charge of the mixer to which water was added simultaneously with the other ingredients. The mixture was always in the ratio of 1:2:4, the stone being 2 in. run of crusher. Concrete was deposited partly by locomotive cranes and partly from cars on narrow-gauge tram tracks.

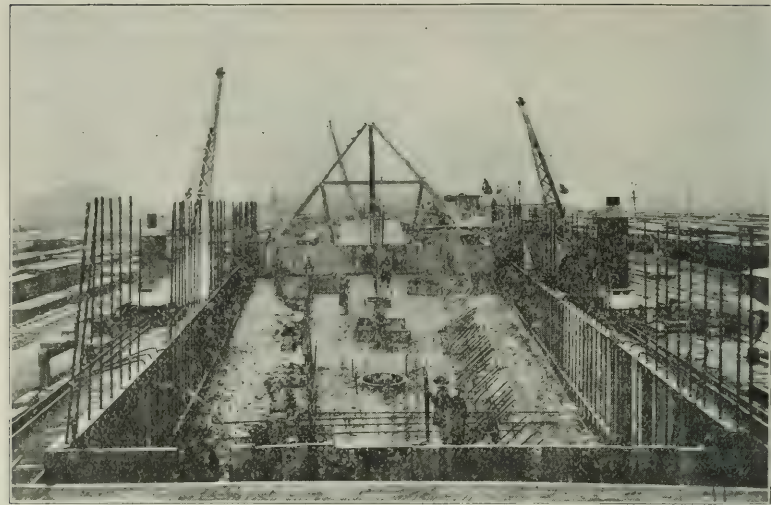


Fig. 7.

In Fig. 7 is shown the state of work on January 28, 1906, at which time the first deck lacked about twenty-four hours of completion. This shows much of the plan of the reinforcement, including the bond to the second deck.

The material locks used were the O'Rourke locks on 3 ft. vertical shafts. The same locomotive cranes were used in hoisting excavated material, as had been used in concreting.

In Fig. 8 is shown an interior view of Caisson No. 1, with its openings into the tunnels.

In construction, after the steel cutting edge had been set up as shown in Fig. 4, it was sunk about six feet lower than there shown and was leveled up at that grade. The base of the walls of the caisson was given a bearing on the mud by tamping it thoroughly under the lagging placed on the stepped forms of the bottom. It was calculated that the bearing power of the soil would be sufficient to sustain the weight of the first deck of concreting until it set. There was considerable settlement, however, during concreting, and more during the interval which elapsed before sinking commenced. This settlement was not uniform, in consequence of which the cutting edge was four feet out of level when the sinking started, and it was necessary to level up the caisson—a difficult thing to do on account of the nature of the material encountered, an old fill of non-uniform quality. It was further complicated by encountering three old sunken barges and some piling directly under the cutting edge. The caisson was finally leveled up without mishap, though to do this, pushed it laterally about twelve inches from the position planned, and the pressure from the outside against

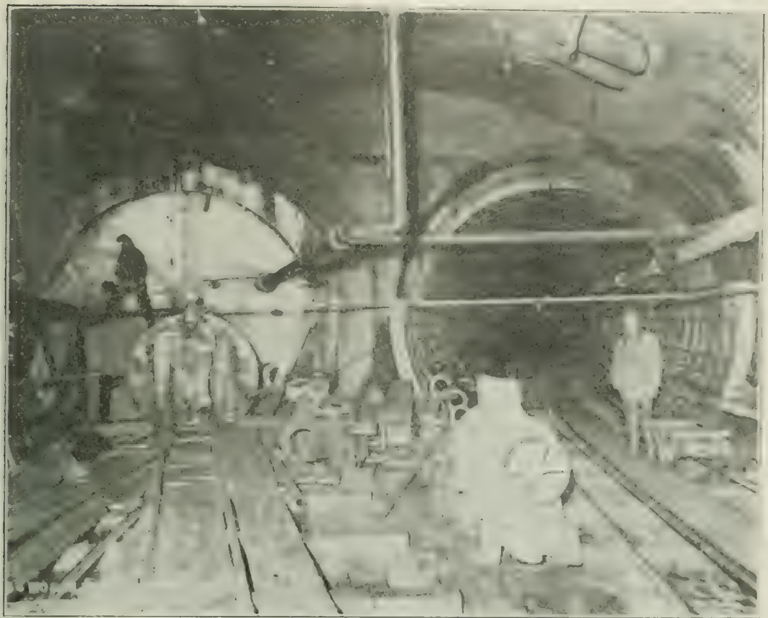


Fig. 8.

the low side was much less for a good part of the distance down than it was on the other side. This operation proved that the green concrete structure could withstand severe strains. Th final grade of the cutting edge was about 83 feet below the surface of the ground, or about 77 feet below mean tide level.

Construction work of the caisson was begun on November 30, 1905. The cutting edge was bolted together by December 14th, and forms and reinforcement were ready so that concreting was started January 18, 1906, and the first deck of concreting was finished January 29, 1906.

The sinking was delayed in starting owing to failure in the delivery of the lock shafting, and did not start until February 26th, from which date until June 6th the sinking continued, with a two weeks' interval only, at the time of construction of the second deck. The invert was placed June 7th-12th, after which the timber forms were taken apart and removed through the lock shafts under normal atmosphere. The south, or lower, tunnel (tunnel "B"), was driven into the east end of the caisson July 5, 1906.

The reinforcement used was all either second-hand railroad rails, or 1 in. square, O. H. steel bars of 0.12% carbon, which bars were delivered to the job as plain square bars. The original plan was to use them plain, but experimental tests showed a considerable increase

in strength by twisting, and accordingly the Turner Construction Company, No. 11 Broadway, New York, was engaged to twist them, for which purpose they set up a twisting plant on the job.

The lower deck was made air-proof, or rather the concrete walls and top of the lower deck were aided in holding the compressed air by the use of a water-proofing process invented by Mr. H. Pashke, Chemical Engineer. A two-ply coating of asphalt saturated canvas, with three coats of a cold solution of asphaltic tar (fluid down to below 32 deg. Fahr.) were used, the application being directly on the inside lagging and hence next to the concrete surface. This material of course came off with the forms.

One feature which makes this work very interesting is the great depth of the working chamber and consequent great surface exposed to the air pressure. It was a bold scheme to make the cutting edge so far below the roof of the chamber and to depend almost entirely on the strength of the reinforced concrete sides and arch to withstand the strains encountered during sinking. This construction demonstrates, perhaps more than any structure previously built, the universal adaptability of reinforced concrete as a building material.

To sink the caisson to its depth (83 feet) required the excavation of about 11,000 cubic yards of material, of which a large amount was of solid rock requiring some blasting, but it was soft enough to be partly handled by means of picks and bull points. It was of course necessary to break it up into pieces small enough to be loaded into the caisson buckets. About 5,000 cubic yards of this material was dumped on top of the caisson after its top had gone below the ground.

The methods used in the design of caisson No. 2, and in its construction and sinking, were almost identical with those employed at caisson No. 1. The trestle had to be higher on account of getting a required 22 ft. clearance over some important yard tracks in the D. L. & W. R. R. Yard, and a 42 ft. bridge had to be provided to cross these tracks to get to a canal where the schooners in which stone and sand were received, and to which also the excavated material was delivered.

Both caissons, Nos. 1 and 2, are in the finished portion of the work (see Fig. 1), and the present traffic passes through them. Caisson No. 3 is built and sunk to its final position. Tunnels C, D, E and F (Fig. 2), are all started from caissons Nos. 1 and 2, but none of the tunnels are yet connected to caisson No. 3, which differs radically from the other two. In the first place it is built large enough for each deck to contain a double crossover instead of only a single turnout, which makes it about 50 per cent. larger in area. Details of the design of this, are shown in Fig. 9. At both caissons, Nos. 1 and 2, it was very difficult to sink the caisson the last ten feet, so No. 3 was designed with the cutting edge relatively 10 feet higher. This leaves it with the steel cutting edges directly

across the middle of the circular tunnels, and these will need to be cut away when the tunnels are connected to the caisson. Placing the cutting edge higher saved a considerable amount of excavation, as the corners at the bottom were left rounded instead of squared out. The shape of the cutting edge was improved by giving it a width of about 6 inches on the bottom instead of having it come to a sharp edge.

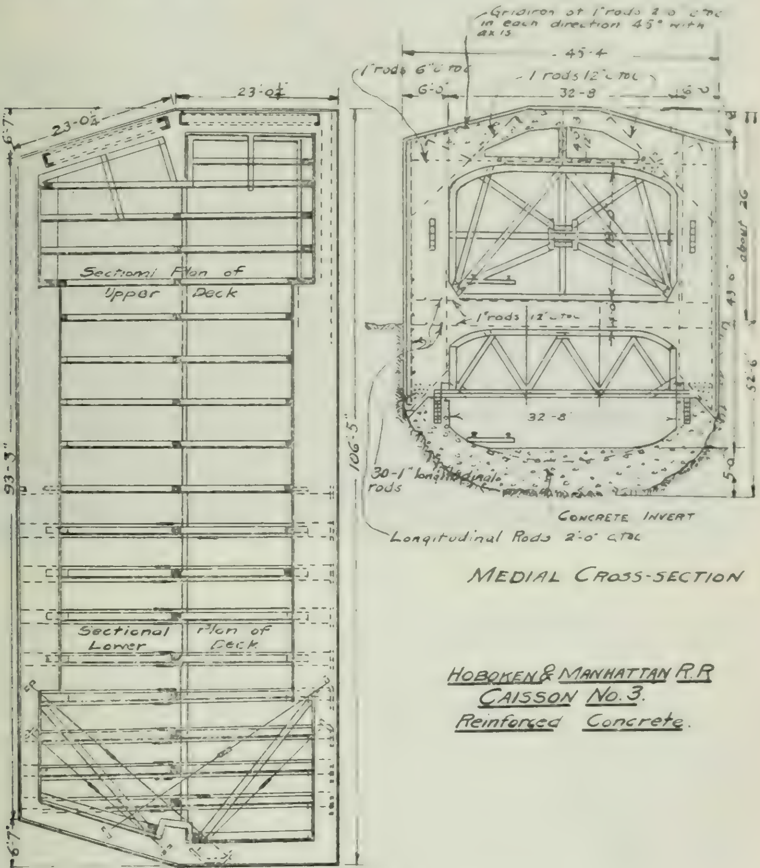


Fig. 9.

The most radical departure from conservative methods, however, was in the sinking. In the other caissons, pneumatic pressure up to 28 pounds above normal was used, but in caisson No. 3 the work was done under atmospheric pressure, which saved the slow work due to removing the excavated material through the air locks, and resulted in a material saving in the labor account, because common laborers took the place of the "sand-hogs." The water was kept

down by pumping, the best results being obtained from the use of steam pulsometers, of which there were five on the job.

In Fig. 10 is shown the cutting edge erected and the sinking started.

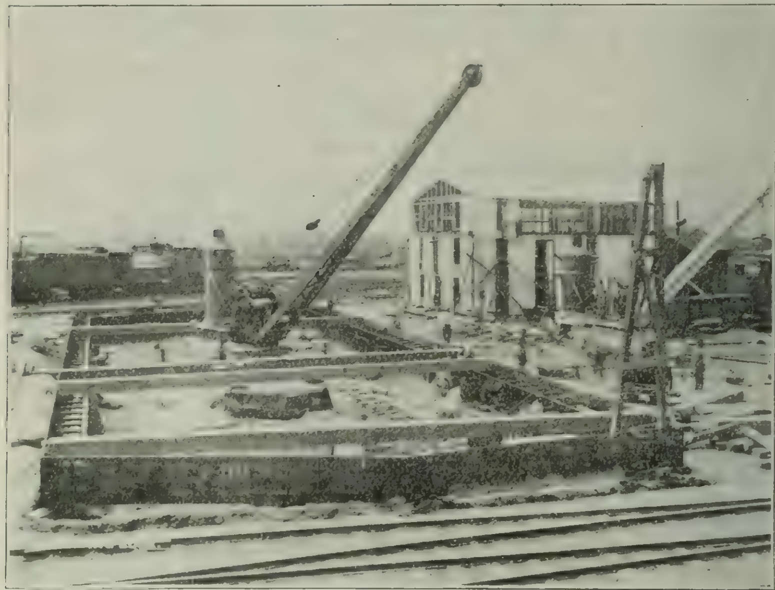


Fig. 10.

Some of the difficult material encountered in this first excavation is shown in Fig. 11, it being an old railroad fill of rock, and an old pile foundation which extended 36 to 40 feet below the ground level. At the top, these piles were arranged in regular rows, but down at about ten feet above their points there was no shape or form to the spacing arrangement. In many cases three or four piles had closed in together a few feet below the top of the ground and followed the rest of the way down together.

The material encountered in all these caissons was nearly the same: viz., about 16 feet, of fill varying from cinders to pieces of trap rock of over 1½ cu. yds.; then 10 to 20 feet, of blue clay, then in turn, quicksand, coarse sand and gravel, and finally about 25 feet of seamy sandstone rock, too hard to pick and shovel easily and requiring blasting. Caisson No. 3 went through all this material without the aid of air pressure, and the cutting edge, from the time concreting began until it reached the rock with 25 feet yet to dig, was buried in the mud from 4 to 8 feet, which helped to keep the water out and the quicksand and other material from coming in. Facilities were at hand at all times, if required to put the working chamber

under air pressure on short notice, and to continue the work without interruption.

The saving to the Hudson Companies by use of the open shaft method, instead of with compressed air, was probably about $30,000.

Fig. 11.

The Hoboken Terminal Station.

This terminal is constructed entirely of reinforced concrete, with the exception of the cast-iron columns and the I-beams in the roof of the concourse. Cast-iron columns were used to save space, it being thought that reinforced concrete columns of sufficient strength would be unsightly on account of their size. I-beams were used in the roof of the concourse in order to make it as shallow as possible to save vertical head-room under the street railroad tracks. About 8,000 cu. yds. of concrete and 600 tons of square twisted steel bars were used in this construction.

Practically the whole of this terminal is directly beneath the busy street car tracks terminating at Hoboken, but the entire work of excavation, timbering, and concrete construction has been carried on without appreciably disturbing the traffic above.

The roof of the terminal was designed to carry a total load of 1,500 lbs. per sq. ft., which was the estimated weight of the roof itself, of the earth back-fill, and of the live load. This unit of 1,500

lbs. was used throughout. The foundation at the west end of the terminal rested on a natural bed of soft, partially disintegrated rock; in the middle, on a bed of blue clay, but for the full easterly half of the terminal nothing was encountered in the excavation but filled-in ground; this, however, was solid and no piles were driven to increase the bearing power. The design assumed that the total weight coming upon the roof was distributed evenly over the foundation, and the bottom was therefore designed for the same unit loading as above stated. The buoyant force due to displacement below sea level was neglected except where actually sufficient to cause flotation, in which case enough weight was added to take care of that feature.

We were indebted to Professor Lewis J. Johnson, of Harvard University, for the formulae used in designing the work. For the most part, use was made only of the formula $M = Kbh^2$, in which M is the bending moment, K a factor worked out by Professor Johnson from the moduli of elasticity of steel and reinforced concrete, and b and h the breadth and height of the section of beam or slab under consideration.

The unit stresses used were 16,000 lbs. per sq. in. tension for the steel, and 500 lbs. per sq. in. compression for the concrete, the values for K being taken on the basis that the modulus of elasticity of steel equals ten times that of concrete. The percentage of reinforcement to the concrete in the cross section is usually 0.6% to 0.8%. In all cases the height—"h"—used, is the distance from the reinforcing plane to the outer edge of the compression side of the slab or beam.

The extreme westerly end was made sufficiently large to erect the tunnel shields, and was also designed to resist an air pressure of 30 lbs. per sq. in. from the interior, as well as to take the exterior strains for which the whole structure is designed.

Fig. 12 shows cross sections taken between the end of the circular bore and the Hoboken terminal. The top and bottom slabs for the clear span of 27 feet are 4 ft. 4 in. in thickness, the analysis of a 12 in. section being as follows:

$$M = \frac{wl^2}{8} = \frac{1500 \times 29^2}{8} = 157{,}700 \text{ ft. lbs.} = 1{,}892{,}400 \text{ in. lbs.}$$

Taking a value of K corresponding to 0.6% reinforcement, and $b = 12$, $M = Kbh^2$, gives a value

$h=46$ in. net depth (4 ft. 4 in., gross depth), and

$0.006 \times 46 \times 12 = 3.31$ sq. in. of reinforcement required.

The spacing of the 1 in. sq. rods was taken at 3.5 in. and the plan shows these arranged in two planes, 7 in. apart in each.

The compression due to reactions from the side walls was neglected, as it would be in the lower portion of the slab and would only tend to reduce the tension therein.

The calculations of the other spans in the roof and floor, and the stresses in the side walls of the station were calculated in the same manner. The unit stress per square foot against the side wall was

also taken at 1,500 lbs. per sq. ft., which is about what the hydraulic pressure from liquid mud at the middle height of the wall would figure. Account was also taken of the vertical load from the roof and base. The vertical walls in this portion of the station are, as shown in the plans, each one foot thick with vertical rods 3 ft. c. to c. near each side. These walls furnish ample bearing for the reaction of the roof and bottom slabs.

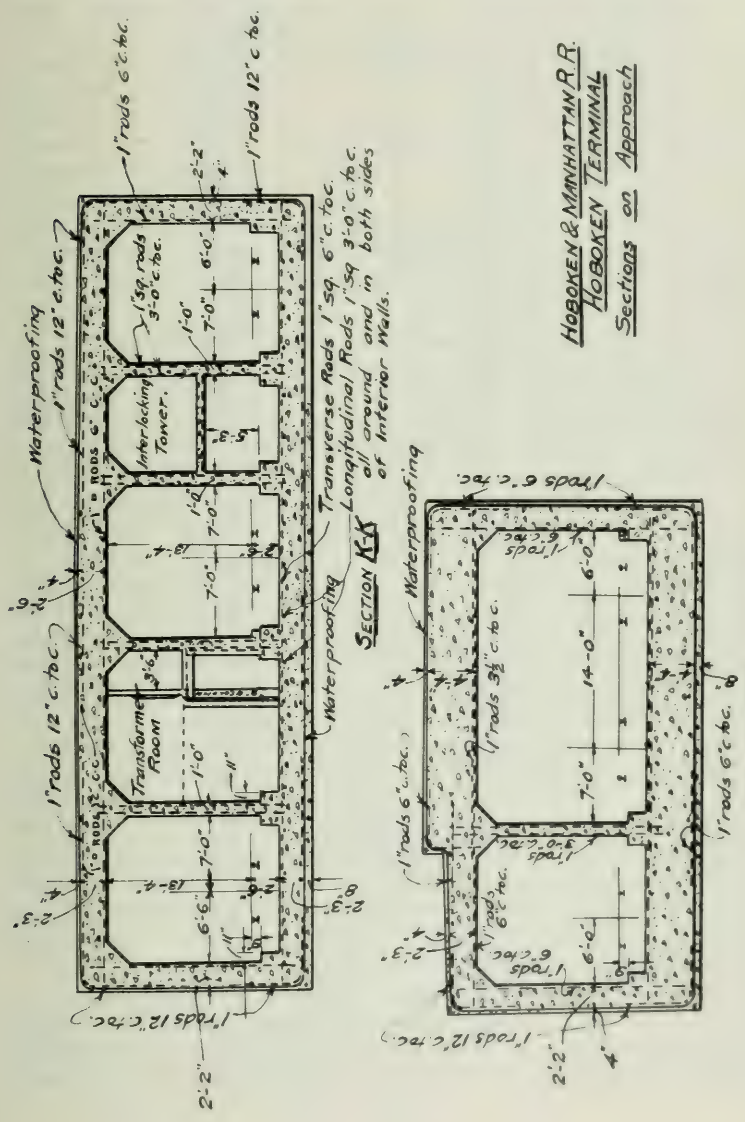


Fig. 12

The roof, base and side slabs were all strengthened by practically shortening the span through the use of counter flexure reinforcing rods. In section KK (Fig. 12) in the roof slabs the tension rods for flexure are placed near the bottom, but by virtue of additional rods placed over the supporting walls near the top of the slab, the span is practically shortened; or, we may say, the slab is practically fixed, and we could probably have used in the analysis $M = wl^2 \div 10$ instead of $M = wl^2 \div 8$, as would be the case in a simple span. The corners are also protected in this same manner by counter flexure rods extending around the corner near the outside for this same purpose. It is believed that these rods so placed have the same effect in fixing the direction of the slab or in shortening the span, as do the rods placed over the support near the surface in continuous spans of horizontal slabs. Thus, in this whole design, all spans either vertical or horizontal were made practically "continuous girders," although in calculating strains and designing the sections no allowance was made for this. To further increase the strength of these slabs, the upper corners were beveled and the lower corner stepped, as shown in Fig. 12.

A typical cross-section of the station proper is shown in Fig. 13, which structurally consists of a system of groined arches above to take the load of the roof, the superincumbent fill, and the street and street traffic above; a system of inverted groined arches below to distribute these loads evenly over the entire surface of the foundation; and side walls proportioned to resist the same stresses as the side walls in the other portions of the terminal heretofore discussed. The groined arches in the base were made pyramidal; that is, plain surfaces were used instead of the curved surfaces in the roof, the object being to save time as well as expensive form work. The reinforcement in the groined arches in the top and bottom is of the umbrella or mushroom type. Sets of three, 1-in. square rods extend from column to column in the direction of the station, at right angles thereto, and also diagonally in each direction, these rods being near the surface of the concrete and being continuous over the supporting columns. Every square 15 ft. by 15 ft. with a column in the center is, with its superincumbent load, supported by that column, and the twelve inch thick concrete bounding the four sides of the square with the reinforcement mentioned is sufficient to carry the uniform load by cantilever or umbrella rib action to the column. In construction, however, the reinforcement was made continuous from column to column in all directions, as well as across the column, thus giving additional strength in the thin portions to better care for any possible concentrated loads.

In order to strengthen the concrete against crushing where the groins rest on the columns, nine 1-in. square, twisted steel rods, about 5 ft. long each, were stood up in the capital, eight slightly inclined in all directions from the vertical, and one extending verti-

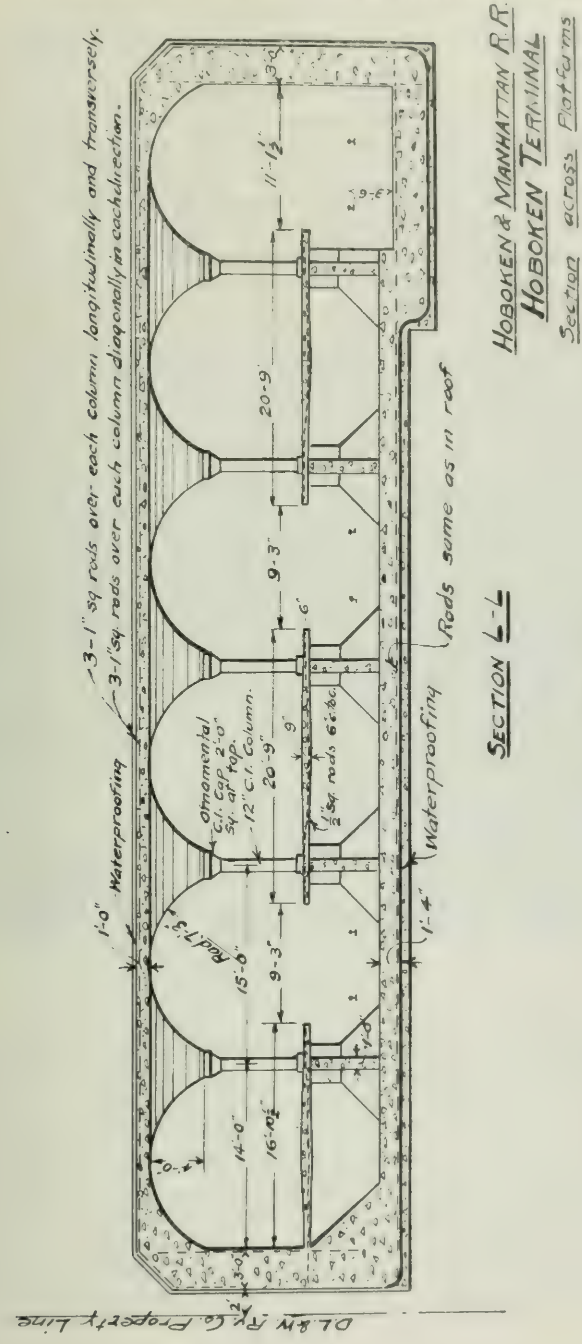

HOBOKEN & MANHATTAN R.R.
HOBOKEN TERMINAL
Section across Platforms
SECTION L-L
3-1" sq rods over each column longitudinally and transversely.
3-1" sq. rods over each column diagonally in each direction.
Waterproofing
Rods same as in roof
Waterproofing
ornamental C.I. Cap 2'-0" sq. at top.
12" C.I. Column.
1/2" sq. rods 6" c. to c.
Rad. 7'-3"
15'-6"
14'-0"
16'-10½"
20'-9"
20-9
9'-3"
9-3"
11'-1½"
3'-0"
1'-0"
1'-4"
D.L.&W. Ry. Co. Property Line

Fig. 13.

cally in the middle of the capital and all bedded in the concrete in that position.

The platforms are reinforced concrete slabs resting on walls one foot in thickness in the line of the columns. The reinforcing iron is continuous over the support and sustains the overhang by cantilever action. These platforms are 9 in. thick at the center of the spans and tapering to 6 in. at the edge, as shown in Fig. 13.

The entire length of the north track opposite the station platform is, as indicated on Fig. 13, a track car inspection pit, the rails being carried on insulating wooden blocks resting on concrete piers, 5 ft. c. to c., thus giving ample room for workmen to move about under the cars. For this purpose the bottom slab of this portion of the station was lowered and thickened to make it similar in design to the bottom slabs in the other portions of the terminal.

In the case of the platforms in the body of the station, a space some 5 ft. high and 13 ft. wide is left below the platform slab. The operating department will probably find this space very convenient for storage purposes.

Notes on Construction.

The site chosen for the terminal was the triangular piece of ground bounded by the D. L. & W. Railroad Yards, Hudson Street, and Hudson Place, Hoboken. This ground, two years ago, was all occupied by the tracks and equipment of the street car line of the Public Service Corporation, two of the tracks coming into the Yard on the elevated incline partially shown in Fig. 14. This figure shows the work at a very interesting stage, the excavation here being nearly completed. It is held open by means of 10 in. by 10 in. timbering between the sheet piling on the sides, while the elevated railroad structure is supported above. Ground was broken for the terminal about the middle of December, 1905, but work was not pushed until the spring of 1906. As the excavation progressed, sheet piling and timbering were placed to hold it open, the sheet piling being, for the most part, not longer than twelve feet and driven by small steam hammer pile drivers, either steam or compressed air, at about 90 pounds per square inch being used. In some cases as many as three sets were used before the bottom was reached. By September 1, 1906, the excavation was complete at the extreme west end, and concreting was commenced. The mixer was a Judd Mixer, and the concrete was transferred from the mixer to its place by Koppel side dump cars on a 24-inch gage track, supported on the excavation timbering. It was possible in a good share of the work to dump the concrete exactly where it was wanted from this track without rehandling. As shown in the plans already referred to, it was necessary to surround the whole work with a waterproofing envelope, which was protected by eight inches of concrete on the bottom and four inches on the sides and top. The waterproofing

material chosen was a burlap saturated with an asphaltic tar solution and an asphaltic tar with a melting point of about 120 deg. Fahr. In the terminal proper (the length of the platform) five ply fabric with six coats of pitch were used. In the portion west of the west end of the platforms three ply cloth with four coats of pitch was used.

The main advantage gained in using the burlap fabric instead of a felt for the waterproofing was the facility in making connection between old and new waterproofing where work could not be made continuous. The envelope of waterproofing is now completed, but because of the large amount of timbering and the necessity of supporting the elevated railroad structure as well as the surface railway east of the foot of the incline, the concrete work, as well as the

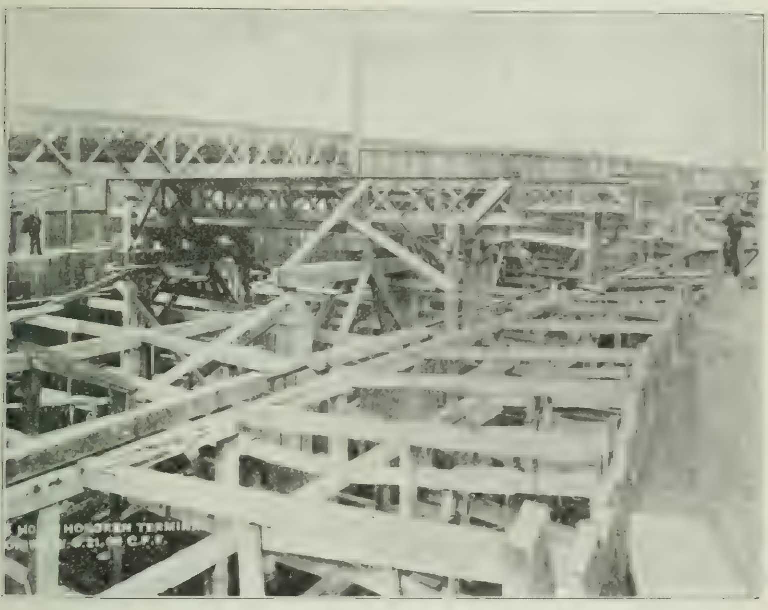


Fig. 14.

waterproofing, was necessarily done in small sections and often with many openings for timbers. This made the waterproofing in some places a succession of patches but in every case where patching was required, or where new work was joined to the older, all the laps were opened up for at least six inches, and the junction in the three or five ply waterproofing was dove-tailed as many times as there were laps. Thus, in the five-ply work for six inches at the junction there would be eleven coats of tar and ten alternating thicknesses of the cloth, making the laps more waterproof than the body of the waterproofing, which could not possibly be the case if felt were used, as it is practically impossible to open up and dove-tail the laps of felt

waterproofing in this manner. Fig. 15 shows the use of clay tile partition blocks for the side waterproofing protection instead of the four-inch concrete called for on the plan. Several thousands of these partition blocks were used in various parts of the work where serious delays might have been caused had concrete been insisted upon. In this view the eight inch bottom protection of the waterproofing has been placed and the waterproofing thereon. After this about two inches of protecting concrete was placed to prevent the waterproofing fabric from being torn by the workmen in placing rods for the bottom slab, and in other work before the slab was placed. The waterproofing had been turned up the side wall a foot or so when placed and, in this view, it is shown pulled away and the

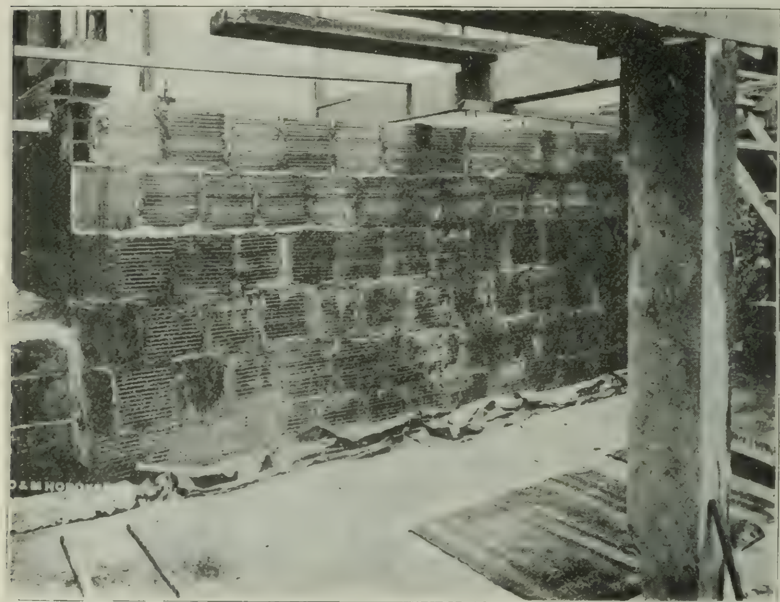


Fig. 15.

laps separated so as to start the waterproofing on the side wall and allow the dove-tailing as described above.

The work is almost entirely below tide so that considerable pumping had to be done in order to keep the excavation dry during the progress of the work. Small ditches dug slightly lower than the general bottom of the excavation led to the sumps and, in order to allow the bottom waterproofing protecting concrete to be placed on a dry bottom, these ditches were bridged over with boards or were tiled. Some of the main ditches were kept open until a later stage to allow cleaning, if necessary, but, after the concreting was practically all done, these ditches were also bridged over and all the

sumps but one were abandoned and filled. The water from this sump was pumped out all through the work by one or more of several kinds and sizes of pumps, but in the end, there remained one large centrifugal pump with a 14 in. suction and a 12 in. discharge and two piston pumps with 5 in. suctions and discharges. Either the large centrifugal pump working alone or the two 5 in. pumps working together could keep the sump from overflowing. To seal this sump the smaller pumps were used, while the suction to the centrifugal pump was changed to 12 in. and with a gate valve. There was first laid down on supporting boards, eight inches of protecting concrete, and then the waterproofing patched in, as elsewhere, flashing this up and around the suction pipes as well as an additional 3 in. pipe with open end, which pipe was extended up through the station to above tide level. After the concrete was fully set, while working the large pump, the small pumps were removed and their suction pipes filled with cement grout, thus closing those outlets. After this grouting had set, the gate valve on the 12 in. suction was closed, and the large pump removed. Some days later the cavity of the sump and, probably, back some distance in the drains, was filled with cement grout through the 3 in. pipe above mentioned. To do this more effectually a tunnel grouting machine, worked by compressed air at 90 lbs. per sq. in., was used, forcing the grout into all cavities. When the grouting was nearly completed, the 12 in. gate valve was partially opened to permit the water to escape and that the grout should fill this pipe up to the gate valve. After this grout had thoroughly set, the valve and the 3 in. pipe were removed, and the openings cemented over flush with the adjoining floor, thus leaving no outward trace of the sump.

The transferring of the vertical loads on the temporary timber posts supporting the street railway structures and the horizontal timbering, was very interesting. At the completion of the excavation the vertical posts were left standing on short horizontal cross timbers resting on the mud bottom of the excavation. In general the tops of these short cross-timbers would be at the general level of the finished excavation and, preparatory to placing the bottom eight inches of waterproofing protection concrete, the posts would be boxed in with 1-inch lumber, 10 inches wide, the box being made slightly larger on the inside than the dimensions of the post. After all the posts in the area to be concreted were thus fixed the eight inches of concrete was placed and finished off to accurate grade. After this concrete had set, the waterproofing was placed and protected with an inch or two of small stone concrete, short 3 by 6 in. timber blocks being placed around the post boxes on the waterproofing so as not to cover that portion of the waterproofing required for waterproofing lap. The vertical posts were then transferred; that is, other posts were set up near these posts on the finished waterproofing, so placed as to relieve the load on the original posts. These latter were then sawed out and removed, the boxes taken out, the holes filled in up to the waterproofing level with concrete, the water-

proofing patch placed, the laps were dove-tailed as heretofore described, plenty of tar always being used in such cases, and then this portion of waterproofing was covered over with the one or two inches of concrete mentioned above. The next stage of work was to bulkhead off with temporary vertical bulkheads, sufficient of the bottom slab of the reinforced concrete for one day's work. The vertical posts were then boxed off with boxes just large enough for the purpose, and of a height slightly more than the thickness of the bottom slab. The reinforcing rods called for in the bottom portion of the slab were then placed, the ends being passed through the bulkheads to bond with the next day's work. Rods in all cases were made continuous by lapping them at least forty diameters at their ends and tying these ends together with two or three wraps of No. 18 pliable wire to hold them in position. The concrete was then placed into the area, being dumped through a shute from the Koppel side-dump cars on the track above. The shutes were moved about so as to require a minimum of rehandling in placing the concrete. If, in the area, the plan called for rods near the upper surface of the slab, these rods would be placed in the wet concrete when it was filled up to the proper level without stopping the concrete, these rods also being passed through the bulkhead if necessary for bond with adjoining work. After this concrete was set the posts were again transferred as before described, the boxes removed, and the holes filled with concrete completing the slab. The posts were transferred in such manner as to allow, without interference, the construction of vertical walls or the pyramids for the column pedestals.

In all of the main station platform portions of the work the next stage consisted in placing the pedestals, columns, and capitals; also the side walls up to the spring line of the arched roof. The groined arch form work was made with great pains so as to leave a finished concrete surface after stripping. Use was made of 2 in. by 4 in. lagging with radial bevel edges; this being made continuous in one direction of arch, the lagging in the other direction being trimmed to fit. A line was marked on the first lagging from center to center of groin across the center of the column, diagonally in each direction, this line being obtained by plumbing down from a chalk line held on the center of the groins. Care was used to run the secondary lagging to this line.

In order to carry the load of the street and the street car traffic above, it was necessary to leave the vertical posts which extend up through this work. They had to be boxed off from the lagging up to the finished top with boxes made large enough for a man to work in after the posts should be removed. After concreting, the loads above were transferred and the posts removed, after which carpenters completed the lagging where broken, and the holes were filled. In transferring these posts much care had to be taken to have the heavy concentrated loads come very close to a point directly over a cast iron column.

The top of the concrete roof came so close to the under side of the horizontal and longitudinal timbers supporting the street and the street car traffic that work was carried on with great difficulty; carpenters worked on the forms with hardly room enough to strike a blow with a hammer; those putting away concrete worked on elbows and knees; and for waterproofing it was necessary to pick out small men and boys in order to do the work at all.

After the waterproofing was finished, except at the posts, it was covered with the protecting concrete called for on the plans, the load was transferred to it, and the waterproofing patched where the posts had been. After this the timbers underneath the ties of the street car tracks and the planking were removed. The ground was filled over the finished station to the original level, and the ballast under and between the ties and the street paving was restored.

In the meantime, all the excavation, timbering and concrete forms inside the station were removed, the one-foot vertical walls to support the station platforms were built and also the reinforced concrete platforms. The granolithic work in the concourse and on the station platforms was made of cement mortar in the proportion of one part of cement and one-half part screened Cow Bay sand, no lamp black or other coloring being used. In building the arched concourse floor and the platform slabs, concrete in its ordinary proportions was placed up to within one inch of the finished grade, the granolithic mortar being added almost immediately in order to be able to count on the whole thickness for strength. The granolithic workers leveled it off and worked it to grade before leaving it for the night.

The concrete mixture, in general, consisted of 1 part of Giant Portland cement (accepted after rigid inspection by the Company's inspectors, and always at least five weeks' old), to 2½ parts of Cow Bay sand and 4½ parts crushed trap rock and gravel. The crushed rock came from the stone crusher of O'Neill & Hopkins, Jersey City Heights, and the run of the crusher was used from two inches to screenings. The gravel was from Long Island, ¾ in. size. The proportions of crushed rock and gravel to make up the 4½ parts of aggregate varied according to the nature of the work. In some cases no gravel at all was used, but usually about half gravel and half crushed rock was employed, and occasionally some small pieces of work were done with gravel only. Wet concrete, according to most modern specifications was used, the degree of wetness being such that when placed in the forms, a man from his own weight would sink into the freshly deposited concrete nearly to his knees. In some of the bulky portions of the work, stones and boulders found in the excavations were imbedded in the concrete. Before placing the concrete in the forms, the face of the wooden forms was filled with paraffine oil to prevent absorption of water from the concrete as well as to aid in making a smooth face on the concrete.

The reinforcing steel used was 1 in. and ½ in. square twisted steel bars, furnished by the Turner Construction Company. They

conformed to the specifications of the Hudson Companies for square O. H. steel bars of 0.12% carbon, to be twisted cold, with one complete turn in a length of eight times the side of the square. Tests made at Columbia University showed that this quality of steel gained about 25 per cent. in ultimate strength and elastic limit by twisting it in this manner. In making hook ends on the rods or any right angle or other bend, they were always bent cold. The rods came to the work in twenty, thirty and forty foot lengths. When other lengths were needed they were sheared to length by the use of Watson-Stillman hydraulic shears—a very ingenious tool, easily allowing two men to make thirty or forty cuts per hour of 1 in. rods.

Tunnel Lining.

A typical cross-section of finished tunnel ready for ballast and track is shown in Fig. 16. The slabs on the central line of the bottom are of reinforced concrete, 14 in. by 30 in. by 2½ in., the rein-

Fig. 16.

forcement being a large mesh expanded metal sheet near the bottom surface of the slab. These slabs cover a drain 9 in. wide by 5 in. deep. The side walls contain vitrified clay tile conduits, twenty holes on one side and fourteen on the other. Additional longitudinal stiffness was given to the tunnel by placing eight 1-in. square twisted steel rods longitudinally in the concrete lining, two on each side of the invert drain and about 6 and 10 inches away from its

edge respectively, and two on each side in the bottom of the side wall. For duct wraps, a single thickness of asphalt saturated cloth, coated with soft tar, was used. These proved to be much more reliable than muslin wraps saturated in grout, as we found practically no joints where mortar from the wet concrete had penetrated into the ducts.

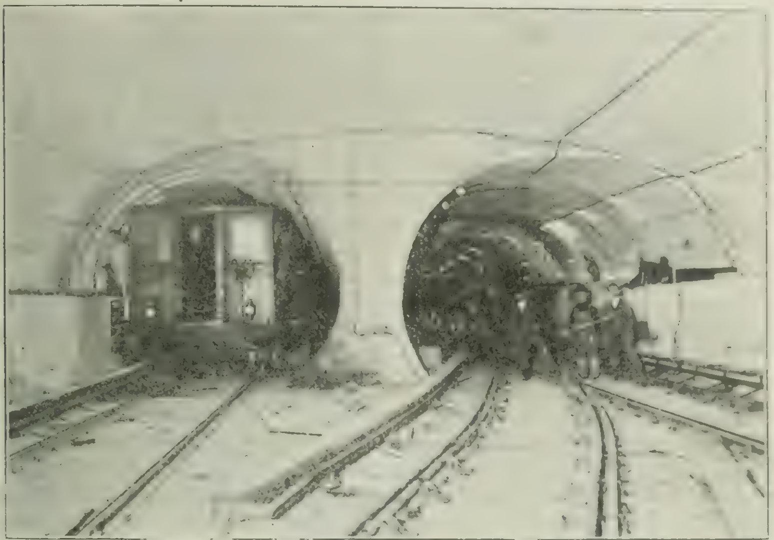


Fig. 17.

In Fig. 17 is shown the tunnel enlargement for crossover on the New York side, which was made from the circular cast-iron tunnels. In the first place two parallel cast-iron tunnels under Christopher Street were driven in the usual manner, and then afterwards, piece by piece, the cast-iron lining was taken out and the reinforced concrete arch substituted. Being so much wider than high, the outside segments of the iron also had to be removed and space made outside to carry heavy concrete walls for the abutments of the over arch and the invert arch. The reinforcement was made continuous all around by lapping the rods through the temporary bulkheads where work stopped for the day. This work was done without losing any ground.

The design and construction of all the work here described was under the direct supervision of Mr. Charles M. Jacobs, Chief Engineer, Mr. J. V. Davies, Deputy Chief Engineer, Mr. G. D. Snyder, Principal Assistant Engineer, and Mr. R. S. Courtney and Mr. V. Messiter, Work Managers.

My own position was Assistant Engineer in charge of reinforced concrete design, and while holding that position I designed Caisson No. 1 and part of the Hoboken Terminal. Later I was Superin-

tendent of Concrete Construction in direct charge of most of the construction herein described.

DISCUSSION.

Mr. John M. Ewen, M.W.S.E: I would ask Mr. Torrance how the tunnel for the Erie tracks, running along to Jersey City, was constructed? Were the caissons made and sunk the same as in the other cases shown?

Mr. Torrance: The tunnels were driven in the railroad yards in the same manner as under the river, the theory being that the circular tunnel will maintain its shape on account of the near equality of pressure from all sides. Of course, where we had to make the tunnel wider than high we had to use some other design, in order to take care of the extra weight above and below as compared to that at the sides. The circular driven tunnels are used everywhere for single track use.

President Loweth: What were the dimensions of the largest caisson?

Mr. Torrance: The length was 106 ft. and the width 46 ft. That caisson was sunk without using compressed air.

Mr. W. B. Jackson, M.W.S.E.: I understood Mr. Torrance to say that they were able to reduce the expense a good deal by not using compressed air. Can he give us an idea of the proportionate amount of this saving?

Mr. Torrance: The cost of concrete construction was practically the same per unit. Of course the largest caisson cost more than either of the other caissons, but on the cost of the sinking there was saved, roughly, one-third, or somewhere between one-third and one-half of the cost of our labor.

President Loweth: Was there not a great saving in time, made by that method?

Mr. Torrance: Not so very much, largely because of the obstacles encountered, in the way of unexpected rock which had to be taken care of. Also, in the first place, a type of pump was selected which proved to be unsatisfactory, and twice during the work the caissons filled with water which had to be pumped out before work could be resumed.

Mr. J. M. Ewen: What air pressure was used?

Mr. Torrance: Up to 28 pounds per square inch, in Caissons Nos. 1 and 2.

Mr. J. M. Ewen: Did the men experience any difficulty in working at that high pressure?

Mr. Torrance: There was very little trouble in the caissons with the men working under compressed air; the large space seemed to have some effect in aiding them to stand it. In the tunnels the men were affected more than in the caisson work. In the tunnel there was a good deal of leakage and the air to make up the loss, coming fresh from the compressor, would be hot, sometimes as high as 90 deg. Fahr.

Mr. J. M. Ewen: How long at one time did the men work under that pressure?

Mr. Torrance: They worked eight hours per day, but were really not in the caisson longer than four hours at a time. Shifts started at eight A. M. and four P. M. and at midnight.

Mr. T. L. D. Hadwen, M.W.S.E.: You made use of a low unit compression stress for the concrete. Do I understand you to say it was only 500 pounds?

Mr. Torrance: Yes, that is right for the Hoboken tunnel.

Mr. Hadwen: Was that unit stress used also on the caisson work?

Mr. Torrance: We used a somewhat higher stress on the caisson work because the heaviest stresses were the temporary ones. We used 25,000 pounds in the steel.

President Loweth: For permanent work the assumed unit strains in the steel reinforcement were 16,000 lbs. per sq. in., and where the stresses were merely temporary during construction, unit strains of 25,000 lbs. were allowed! Is that correct?

Mr. Torrance: Yes, sir, as in caisson No. 1 it was designed as an alternate to the steel design in which those units had been employed.

President Loweth: Even with those high strains you had no cracks, I believe.

Mr. Torrance: We did not even have any hair cracks, although when we started the sinking, the concrete was green. In Caisson No. 3, the first concrete placed weighed about 3,000 tons, and while placing it, the caisson sank over 7 ft., plowing its way down and without cracking.

Mr. Ernest McCullough, M.W.S.E.: In reference to the low unit stress mentioned by Mr. Hadwen, for the concrete, this stress depends upon the value chosen for the ratio between the moduli of elasticity of the steel and the concrete, which is termed "n." Mr. Torrance stated that this value of "n" was taken as 10 in his formula, thereby making it possible to get a value of 500 pounds fibre stress in the concrete, and 16,000 pounds per square inch in the steel. If he had used the value of "n" equals 12, as required by the building ordinances of the city of Chicago, he would have been unable to use a higher stress than 10,000 pounds in the steel, if he had used 500 pounds in the concrete. Using, then, this raio as required by the Chicago building ordinance, the actual stress in this concrete is nearer 580 pounds than it is 500 ponuds.

Mr. Torrance: In the design of the Hoboken terminal the table for value of "K" as determined by Prof. Johnson, for "n" = 10, was used. For myself I am too unfamiliar with the derivation of the formulae to properly discuss whether this is strictly correct, but of course that "K," was used, which gave the greater amount of steel, whether it was "Kc" or Ks.

Mr. McCullough: Was any investigation made as to the possible disintegrating effect of the concrete, where the rods were in the side, on account of the skin friction?

Mr. Torrance: We did not consider that at all. There was undoubtedly some such strain, but our boards were planed. In caissons Nos. 1 and 2 especially, there was hardly any skin friction. It went down with compressed air, buoying it up, and the bubbling of air and water, on all sides, prevented skin friction being very great.

Mr. McCullough: It seems to me there would be some disintegrating effect.

Mr. Torrance: In designing caisson No. 3, the designer in the main office of the Company used smaller angles and did not provide threaded holes for the rods. We spaced the rods out by means or boards, fastened to the lagging, which boards were removed as the concrete arose. The designer was afraid that water would get to the rods from the outside along the angles, if they were used as in Caissons No. 1 and No. 2.

Mr. McCullough: I think that this method of spacing with the boards, without fastening the rods to them, is better, for fastening the rods to channels attached to the caisson sheeting would certainly affect the material if the sheeting moved, and would put some initial stress on the steel.

Mr. M. F. Ewen, M.W.S.E: In regard to that wet concrete, where you speak of having gone in up to your knees; how long did it take, for it to set?

Mr. Torrance: The first concrete in Caisson No. 1 was put in, in January at a temperature of about 35 deg. Fahr. That concrete was very slow in setting, on account of the cold weather. The cement was some we had had on hand for sometime, which added to the slowness in setting. In one place I saw a man go in up nearly to his waist after the concrete had been deposited nearly 24 hours, In summer, however, when the other two caissons were constructed, some of it set so rapidly that one could walk on it inside of five or six hours.

Mr. M. F. Ewen: What was the reason for changing the cutting edges?

Mr. Torrance: The cutting edges of Caissons No. 1 and No. 2, were badly wrecked on the way down; the rivets would break and the two plates would separate from each other, making a wreck of the cutting-edge by the time it got down to the bottom. We left six inches width at the bottom of Caisson No. 3 so we could have a place to block up under.

President Loweth: How efficient was the waterproofing in making the caisson water tight? Was the tightness due to the good quality of concrete or to the waterproofing?

Mr. Torrance: We did not do anything to the waterproofing except to use 1:2:4 concrete; we made the work continuous. There was no waterproofing, but the caissons were very tight. There were one or two leaks in caisson No. 2, and the Superintendent in charge of the sinking, drilled a hole out through that place and pumped grout through until he stopped the leaks. That method was

followed a good deal, especially in the enlargements under the streets of New York, where they enlarged from the inside, by patch work. In Hoboken we used the waterproofing envelope.

President Loweth: Was the waterproofing successful?

Mr. Torrance: I might say almost perfectly successful. About all the water that comes into the whole Hoboken terminal, could be put through a ¾ inch pipe. There were a few leaks where our work joins on to the D. L. & W. property. At that junction where felt waterproofing joined on to our asphalted burlap method, some considerable leakage occurred. We gave up trying to stop it there, and embedded pipes under the surface to collect it, carrying it down through the floor and let it run into the ballast of the track. But for the most part, the waterproofing was successful.

President Loweth: The speaker is of the opinion that the best way to make concrete waterproof is to make it of excellent quality.

Mr. Torrance: When we put in the invert of Caisson No. 1, there was some talk about waterproofing that. We made some tests on some waterproof cement, and concluded that ordinary Portland cement was about as good as waterproof cement. The manipulation is of more importance than the so-called waterproofing qualities of the cement. It was finally decided to use ordinary Portland cement in the bottom—with the 1:2:4 mixture. This proved entirely successful.

Mr. C. R. Dart, M.W.S.E.: I have not been able to make concrete absolutely waterproof on account of the joints. I have not used much concrete of the 1:2:4 mixture, most of what I have used being 1:2½:5 and 1:3:6. In the Chicago river we have made our pits watertight by lining with grout, making a continuous lining, and have had fairly satisfactory results. In one or two cases a little too much mortar was used, which made the lining porous, but we have had very little leakage. In one case we tried a steel lining, which was not successful. Our best results were at Dearborn Street bridge, which has practically no leakage.

Mr. Hadwen: Referring to the summer work, where they had that large area of concrete, could they get it in place and the next layer of concrete started without having a joint? Were there not some horizontal joints?

Mr. Torrance: If there were any horizontal joints, they did not give us any trouble. We always managed to cover any place which was about to set hard, before it was really hard, and make a joint as small as possible. We took pains to have men walk in it and make it rough on the surface when taking initial set, so there would be more or less of a bond with the new concrete when it should be put on. In the summer time, on account of anticipating that there would be trouble like that mentioned, it was put in faster. We put in the second deck of caisson No. 2 in nine shifts—four-and-a-half days, working two shifts, doing that 1,500 yards of concrete in those nine shifts, so as to avoid the trouble spoken of.

THE HEAT LOSSES FROM STEAM TURBINES

AN EXPLANATION

Editor Journal Western Society of Engineers.

In the JOURNAL for August, 1908, Vol. XIII, page 549, Prof. J. C. Thorpe, in a paper on steam turbines, listed the energy losses occurring with turbines as follows:

1. Friction between the steam and the metallic surfaces, both stationary and moving	10%	12%
2. Friction due to eddy currents	5%	7%
3. Resistance to the rotation of moving parts in the atmosphere of steam, called "windage"	6%	8%
4. Mechanical friction in journal bearings, glands, stuffing boxes, etc.	5%	10%
5. Leakage through clearance spaces, glands, etc.	3%	7%
6. Radiation loss		
7. Residual velocity in exhaust		
	4%	8%

In discussion on page 571, I stated—

> I think it unfortunate that as a general thing there has been so little discussion of the factors which influence efficiency with turbines. After all, when the matter is summed up, it would appear there are only three possible sources of loss, to-wit:
>
> a. Heat in the exhaust,
>
> b. Radiation from the exterior of the machine,
>
> c. Velocity in the exhaust,
>
> and strictly speaking, I do not think that Items 1, 2, 3, 4 and 5 given as losses on page 549 of the paper, should be so considered for the following reasons:
>
> Friction between steam and the metallic surfaces must result in the generation of heat. This heat is either returned to the steam flowing through the machine or else radiated away from the exterior of the casing, but inasmuch, however, as it cannot raise the temperature of the turbine casing from that due to normal condition, it could not contribute to the radiation loss, therefore the heat would find its way into the steam to be transferred into work, or else would escape with the exhaust. The same reasoning applies to friction due to eddy currents, likewise the resistance of the steam to rotation known as windage.

Later, Prof. G. A. Goodenough in a written communication appearing on page 574, said:

> In the question brought up by Mr. A. Bement regarding the losses in the steam turbine, we must take issue with Mr. Bement's statement that Items 1, 2, 3, 4 and 5 of page 549, should not be considered as losses. Take the case of Item 3, Resistance to the Rotation of Moving Parts in Atmosphere of Steam, or Windage. Here work is converted into heat, and as Mr. Bement states, the heat is returned to the steam in subsequent stages. To be sure, there is no loss of energy; that is, our law of conservation of energy is not violated. There is, however, a loss of availability; that is, the heat that has been produced by the work can in no way in the subsequent stages be made to give back the work that was expended in generating it. In fact, it can be made to give back only a very small fraction of that work.
>
> For example, suppose that in a given stage 10,000 foot-pounds of work are expended in windage. This means that the equivalent of 10,000 foot-

> pounds is produced as heat at some definite temperature. Now if the thermodynamic efficiency of the turbine reaches the high value of 20%, then not more than 20% of the 10,000 foot-pounds can be recovered as work; the remaining 80% must inevitably be lost.
>
> The same statements may be made of the other items, Friction between the Steam and Blades, Friction Due to Eddy Currents, etc. These losses are good examples of the real meaning of the second law of thermodynamics, or in a broad sense, the law of degradation of energy. All of these frictional processes are irreversible and give rise to a certain loss of availability.

A superficial reading of the discussion might convey the idea that my reasonings are at fault, which could not occur had Prof. Goodenough followed the matter further. Thus the problem may profitably have additional attention.

It is first necessary to obtain a definite understanding of what may strictly be defined as losses. Following this inquiry it is apparent that energy passes from the turbine as follows:

To the electric generator,

As heat in the exhaust steam,

As radiation of heat from the exterior of the machine,

As velocity in the exhaust,

The sum of the four being 100%.

In the first no loss occurs because energy is imparted to the generator and is usefully expended. The other three do no useful work and are therefore losses, and as these four paths for the flow of energy are the only ones from the turbine, it must necessarily follow that the sum of the three latter constitute the total loss. It makes no difference how unfavorable conditions may be inside the turbine, they do not constitute losses, because a condition of loss cannot exist until the energy has left the turbine, and it is the fact of its leaving, that constitutes the loss. Prof. Goodenough concedes this point by saying, "To be sure, there is no loss of energy; that is, our law of conservation of energy is not violated."

Thus at this point these frictional effects have expended themselves and are at an end, and the result is that the energy generated thereby is in the form of heat in the steam, thus not lost. It therefore necessarily follows that these frictional effects are not losses, as has been stated.

But this energy which is in the form of heat in the steam, shares the same fate as the heat which comes direct from the boiler, because the turbines are able to recover only a small part of it.

It therefore seems clear that while these frictional effects are not losses, they are undesirable conditions, or in other words, are operations which cause losses to occur, instead of, strictly speaking, being themselves losses. It would probably make the matter clearer to many of us if this is realized, and it would, no doubt, be more to the point if instead of classifying these effects as losses, they be considered as conditions which result in losses.

Very truly yours,

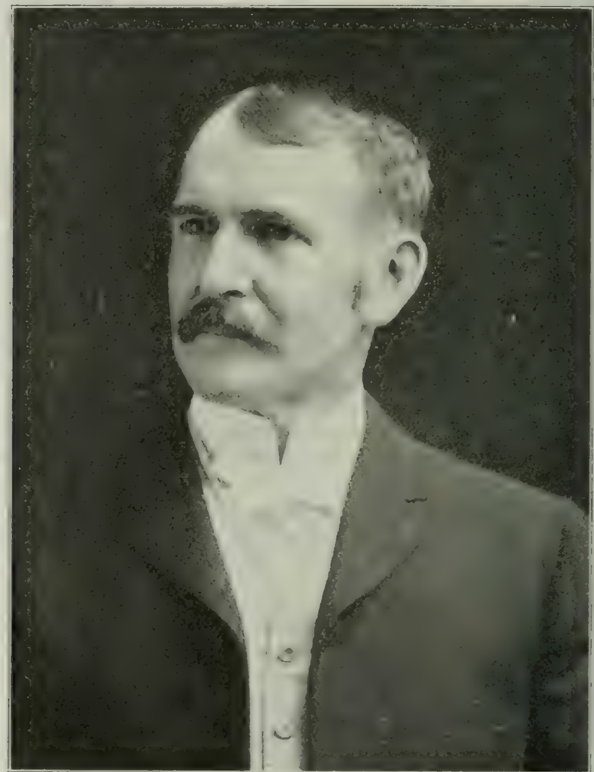
(Signed) A. Bement.

IN MEMORIAM

Elbridge Harlow Beckler.

August 26, 1908.

Elbridge Harlow Beckler was born in Boston, Mass., October 16, 1854, and moved with his parents when about 9 years of age, to Livermore Center, Maine. Previous to entering the Maine State College, at Orono, he had taken a preparatory course in the Maine Wesleyan Seminary, at Kents' Hill, where his special ability in



mathematics had carried him so far beyond the regular classes that he was enabled to enter the Junior class in college, from which he graduated in the year 1876, with the degree of Civil Engineer.

In the spring of 1877 he went to Minnesota to seek work in railway construction, but finding it necessary to take up any work that offered, on account of the slow recovery in business conditions from

the panic of 1873, he spent the next two years in teaching, farming, surveying and map making. His railway career dates from 1879, when he became Transitman and Assistant Engineer on the St. Paul, Minneapolis & Manitoba R. R., at Fergus Falls, Minn. In the following year he entered the employ of the Northern Pacific Railway as Locating Engineer. The road was then constructed to a point about 60 miles west of Mandan, N. D., and the major portion of the location westward, from where Glendive, Montana, is now situated, along the valley of the Yellowstone River and beyond to Helena, Montana, a distance of about 400 miles, was made by parties under Mr. Beckler's charge. Following the completion of this portion of the location he was placed in charge of forty miles of the heaviest construction on the line, including the 3,610 foot tunnel at Bozeman Pass. His connection with the Northern Pacific lasted from 1880 to 1886, with the exception of six months in 1881, when he was engaged in location and construction for the Canadian Pacific Railway along the Kicking Horse River, west of the summit of the Rocky Mountains. During this period also the construction of a bridge 6,000 feet in length across St. Louis Bay, for the entrance of the Northern Pacific into Duluth, Minn., was placed in his charge.

In 1886 Mr. Beckler entered the service of the Great Northern Railway, in the location of the Montana Central, which was the beginning of the Great Northern extension to the coast. Rising rapidly through the positions of Locating Engineer, Assistant Engineer and Assistant Chief Engineer, in 1889 he was made Chief Engineer in charge of the entire work to the coast, about 1,000 miles, from Central Montana to Puget Sound. In this position, which he held to the completion of the work in 1892, he accomplished the most notable achievement of his life.

In 1893, after fourteen years of constant, active engineering work in the west, Mr. Beckler moved to Chicago, Ill., and, making this city his headquarters, engaged in various pieces of work in the line of his profession, acting principally as Consulting Engineer. During this period he constructed a narrow-gauge railroad in Arizona for the United Verde Copper Company.

In 1896 he entered the service of Winston Brothers, contractors, and remained in their service until 1902, when he became a stockholder and director in Winston Brothers Company, a corporation formed by the reorganization of Winston Brothers. At the time of his death he was actively engaged in the work of his company in connection with the coast extension of the Chicago, Milwaukee & St. Paul Railway. Among his other duties in this connection was the supervision of the work on the tunnel through the Bitter Root Mountains at St. Paul Pass, in Shoshone County, Idaho, and he should share in the credit for the record-breaking progress recently reported on this work. For work of this character he was excellently qualified by his past experience in tunnel building on the Northern Pacific and Great Northern Railways. His death was

sudden, with no forewarning, and was caused from cerebral hemorrhage.

Mr. Beckler was married in 1880 to Miss Mera Rogers of Richmond, Maine, who, with two daughters, now residing in Chicago, survives him.

Mr. Beckler was a member of the Western Society of Engineers, the American Society of Civil Engineers, and an honorary member of the Montana Society of Engineers, of which latter society he was a charter member, and which he was largely instrumental in organizing.

A more fitting tribute cannot be paid to the life and character of our deceased member than by quoting the following words from a personal letter of condolence written by Mr. Chas. J. Morse to Mrs. Beckler:

"My acquaintance with Mr. Beckler began at Helena, Montana, when he was Chief Engineer of the Great Northern Railway, and I was Consulting Engineer of the Edgemoor Bridge Company, and it was in connection with the building of the Columbia River Bridge. I traveled with him, overland, along the unfinished line of railroad, to the site, spent several weeks in professional intimacy, and we became quite intimate friends from the beginning. I had and have always had a very great respect for his professional attainments, experience, originality and courage; and I had and have a still deeper regard for his high ideals, his devotion to right and duty, his scrupulous integrity, his keen sense of justice, and all those fine qualities of mind and heart which go to form that highest attainment and richest legacy of this life—character."

W. C. Armstrong,
W. H. Finley,
W. O. Winston,
Committee.

Zimri Allen Enos.

Zimri Allen Enos died at his home in Springfield, Illinois, December 8, 1907, at the age of 86 years. He was born in St. Louis, Missouri, September 29, 1821. At the age of 2 years the family moved to Madison County, Illinois, and a little later following his father's appointment as Receiver of Public Lands in the Springfield District, the family moved to Sangamon County, Illinois. Here the father, in company with his associates, laid out the town of Calhoun, now Springfield.

His father died when the lad was 11 years of age. His early mental training was acquired in a log school house, but later he became a student in Springfield Seminary, the Jesuit University of St. Louis, and Illinois College of Jacksonville. His desire to follow civil engineering as a profession led him to choose studies that would

be of most benefit to him. However, after leaving school he entered the law office of Baker and Bledsoe and finally was admitted to the bar. At that time the Springfield Bar numbered among its members some of the most noted and eminent members of the legal profession, including Abraham Lincoln, Stephen A. Douglas, Stephen T. Logan, Lyman A. Trumbull and others.

After a time, however, he left the profession of the law to become a commission merchant. He followed the commission business about three years and then resumed the pursuit which claimed his attention in his earlier years—surveying and civil engineering. He filled the position of County Surveyor of Sangamon County for two terms, served as alderman ten years, and for a similar period was a member of the Board of Education, largely promoting the cause of schools through his earnest and effective efforts.

In 1846 he married Miss Agnes D. Trotter. Unto Mr. and Mrs. Enos were born six children—four sons and two daughters—all of whom are living except one son, William. Mrs. Enos died in May, 1906, at the age of 71 years. One son, Allen Z., is County Surveyor of Sangamon County, and another son, George T., is associated with him in this office.

On November 6, 1878, Mr. Enos became a member of the Civil Engineers' Club of the North West, now the Western Society of Engineers, and for nearly thirty years he was an honored member of this Society.

Mr. Enos presented one paper before this Society on "The Proper Mode of Subdividing a Full Government Quarter Section," and several papers written by him for the Illinois Society of Engineers and Surveyors, of which he was a member, are of much interest:

"The Subdivision of Fractional Quarter Sections. What is a 'Half-quarter Section, viz., 80 Acres,' Applied to Fractional Quarter Sections?"

"What are the Principles and Rules of Law that are to Determine the Exterior Boundaries of the Government Township?"

"By what Mode are the Unestablished Quarter Section Corners on the Township and Range Lines to be Made for the Fractional Sections along those Lines?"

"The True Exterior Boundaries of Townships."

"By what Rules of Law are Course, Distance, and Area Governed, in the Subdivision of the Government Sections?"

"Consideration of a Law Compelling the Recording of Private Surveys."

"The Early Surveyors and Surveying in Illinois."

These papers contain much of value to surveyors. The paper on the "Early Surveyors and Surveying in Illinois," is of special interest since it contains a fac-simile of an opinion of Abraham Lincoln on the proper method of subdividing a section of land; also fac-simile of a survey made by Abraham Lincoln in 1836.

Mr. Enos was a prominent Mason. The funeral services at the

residence and the grave were in charge of Elwood Commandery of the Knight Templars, of which he was a member.

In life he was a well preserved man and apparently hale and hearty up to within two days of his death. He was ever deeply interested in whatever pertained to the intellectual, material and moral development of the community. His life grew richer and stronger with passing years—stronger in those qualities which are the basis of an honorable manhood and which command respect and honor in every land and clime. No history of Springfield would be complete without the mention of this man, who was not only one of the revered patriarchs of the community and one of her oldest citizens, but also because his life has ever been honorable, his actions sincere and unaffected, and his loyalty and friendship above question.

F. G. Ewald,
E. C. Carter,
L. P. Morehouse,
Committee.

MINUTES OF THE MEETINGS

Regular Meeting, September 2, 1908.

A regular meeting of the Society (No. 637) was held Wednesday evening, September 2nd, in the new quarters on the seventeenth floor of the Monadnock Block.

The meeting was called to order at 8:25 p. m., with President Loweth in the Chair, and about 55 members and guests present. The reading of the minutes of the June meeting was dispensed with by consent, as they had been published in the June Journal.

The Secretary reported from the Board of Direction their action at a meeting held September 1st, of the election into membership in the Society of the following:

	Grade
S. P. C. Borson, Malta, Mont.	Associate
Wm. L. Six, Chicago	Active
Laurence P. Ryan, Chicago	Associate
Smith T. Henry, Chicago	Associate

Also that an application for membership in the Society had been received from Mr. Harry Francis Kellogg, of Chicago.

Announcement was made of the death on August 28th, of Mr. E. H. Beckler, of Chicago, an active member of the Society. Mr. W. C. Armstrong offered a resolution that a committee of three be appointed by the President to prepare a Memorial of this late member, to be published in the customary manner in our Journal. The resolution was approved by vote, and the President announced the appointment of Mr. W. C. Armstrong, Chairman, Mr. W. H. Finley, and Mr. W. O. Winston.

There was no further business brought before the meeting, but President Loweth congratulated the Society and the Building Committee on the completion of the work of preparing the new quarters of the Society and on being able to hold the first meeting for the fall and winter session of 1908 in the new Assembly Room. He also stated that it was expected to have a "house-warming," in the form of a "Smoker," some evening the latter part of October.

The President then introduced Mr. H. von Schon, M.W.S.E., of Detroit, who read his paper on "The Analysis of a Hydro-Electric Project." This paper had been printed and sent out in advance of the meeting. The author made some blackboard sketches in illustration of some parts of his paper, and after its presentation some stereopticon views were shown, illustrating the construction of a hydro-electric plant on the Patapsco river, near Baltimore, which was unique in that the turbines and electric generators were placed within or under the concrete-steel dam.

Discussion followed from Messrs. L. K. Sherman (by letter), L. E. Cooley, W. L. Abbott, the President, and the author of the paper. The meeting adjourned at 10:45 p. m.

Regular Meeting, Wednesday, October 7, 1908.

A regular meeting of the Society (No. 639), was held Wednesday evening, October 7th. The meeting was called to order at 8:30 p. m., with Past-President Abbott in the Chair, and about 40 members and guests present. The minutes of the preceding meeting held September 2nd, were read and approved. The Secretary reported from the Board of Direction, that applications for membership had been received from:

	Grade
Arthur M. Houser, Chicago	Active
Neet C. McCanliss, Missoula, Mont.	Active

The Chairman introduced Mr. L. R. Stowe, who presented his paper on "Methods of Studying the Heat Absorbing Properties of Steam Boilers," which had been printed and sent out in advance of the meeting. Lantern slide views were also shown in illustration. Discussion followed from Messrs. W. L. Abbott, A. Bement, W. T. Ray, R. H. Kuss, C. W. Naylor, Arthur Frith, with a closure by Mr. Stowe. The meeting adjourned about 10:30 p. m.

Extra Meeting, October 21, 1908.

An extra meeting of the Society, No. 641, was held Wednesday evening, October 21st. The meeting was called to order at 8:30 P. M. by President Loweth, with about forty members and guests present.

There was no business to bring before the meeting, and Mr. A. N. Johnson, M.W.S.E., was introduced, who presented an abstract of his paper—"Specifications and Notes on Macadam Road Construction," this paper having been printed and sent out in advance.

Discussion followed from President Loweth and Messrs. F. M. Button, E. N. Layfield, M. G. Nixon, D. W. Roper, and E. E. R. Tratman, with a closure by Mr. Johnson.

J. H. Warder,
Secretary.

ELECTRICAL SECTION.

Minutes of the Meeting, September 25, 1908.

Minutes of the Meeting of the Electrical Section, September 25, 1908.

The first meeting of the Electrical Section No. 34 (being No. 638 of the Society), for the season of 1908-9, was held Friday evening, September 25th. Owing to some temporary trouble with the lighting system the opening of the meeting was delayed half an hour. Chairman D. W. Roper presided, with about 60 members and guests present. The reading of the minutes of the last meeting of the Section, held May 8th, was dispensed with as they had been published in the Journal.

The Chairman introduced Mr. F. A. Sager, of The Arnold Company, who presented some "Notes on the St. Clair Tunnel Electrification," with lantern slide illustrations. The subject was discussed by Messrs. M. K. Trumbull, W. L. Abbott, P. Junkersfeld, D. W. Roper and Dr. W. A. Evans. The meeting adjourned about 10:45 p. m.

Minutes of the Meeting, October 16, 1908.

A regular meeting of the Electrical Section, No. 35, (being No. 640 of the Society), was held Friday evening, October 16, 1908. The meeting was called to order about 8:20 p. m., by Mr. D. W. Roper, Chairman, and about 60 members and guests present. The minutes of the preceding meeting, held September 25th, were read by the Secretary and approved.

The Chairman then introduced Mr. H. B. Gear, M.W.S.E., who presented his paper on "The Development of an Alternating Current Distributing System." The address was illustrated with lantern slide views. Discussion followed from Messrs. D. W. Roper, G. H. Lukes, Hayward Cochrane, J. R. Cravath, and P. Junkersfeld, with a closure by the author.

The meeting adjourned about 10 p. m.

J. H. Warder,
Secretary.

The Excursion to Gary, Indiana.

Members of the Western Society of Engineers, and friends had an enjoyable excursion to Gary, Indiana, on Thursday, October 8th, 1908, as guests of the Indiana Steel Company, whose plant there, is now in course of construction. There were about 160 in the party, who took the 10:45 A. M. train on the Lake Shore Road. On arrival many went to see the town

itself, which is south of the railroad. What had been a sand barren with scrub oaks but a year or two ago, now presents a good appearance with paved streets and side walks, a sewer system and water works under construction, (Messrs. Alvord and Burdick, Engineers) and many substantial stone, brick or frame stores and houses, including banks and hotels. The housing accommodations are yet inadequate for the large force of men engaged in the Steel Plant; a very large number of whom live in adjacent towns, and as far off as South Chicago.

Lunch to the party was served in the large dining room of the North Works Inn. At the conclusion Mr. John Brunner, M.W.S.E., welcomed the guests to the plant in the name of the Steel Company, and to which President Loweth made a reply for the Society.

At the Steel Company's Office Building, near the entrance to the Plant, the party was met by Mr. W. P. Gleason, General Superintendent, who had made provision to take them through the Works

The company was divided into a number of smaller parties, to each of which guides connected with the works were assigned. The works are not yet manufacturing steel, but a visitor had all the better opportunity to obtain an idea of the magnitude of the plant from what there was under construction. The Steel plant occupies about 1,500 acres out of a total of 9,000, belonging to the companies. A slip has been dredged in from the lake to take in the ore carriers from the upper lakes, and which are unloaded in a very short time by the most approved form of ore handling machinery. There are eight blast furnaces adjacent the ore docks, and space provided for eight additional furnaces for construction in the future. The waste combustible gases from the blast furnaces will be washed and purified, and used in large double gas engines of 2500 H. P. each, for generation of electrical energy. This will be distributed about the plant, where it may be required for power. Electric motors will be used wherever possible, even to the driving of the heavy blooming mills and billet trains. The steel will be made by the open-hearth process from the blast furnace metal, which will generally be delivered in a molten condition to the open-hearth furnaces. These are of 60 tons capacity, arranged 14 in each of two large buildings, with space reserved for four additional buildings of equal size and capacity. The Rail Mill and the Billet Mill are of very large size and laid out in an admirable manner. All of the construction work is of the very best and of a most substantial character. But the afternoon was all too short to get more than a very superficial knowledge of this immense plant.

The party left there about 5 P. M. for their return to the city, greatly indebted to the Steel Company for the courtesies shown.

BOOK REVIEWS

THE PRINCIPAL SPECIES OF WOOD: Their Characteristic Properties. By Charles H. Snow, C. E. John Wiley & Sons, New York. 1908. Second edition. Revised and enlarged. Price $3.50.

Now that the unpleasant fact has been realized that the timber resources of the United States are being depleted some three or four times as fast as the forest growth restores them, and that there is danger of a timber famine within one-third of a century, engineers are taking heed. They are becoming more careful in the selection and use of this indispensable material and they are seeking for facts to guide them as to what it is best to do. Hence a number of works have lately been published to supply information. Among these is the book of Mr. Charles H. Snow, Dean of the School of Applied Science, New York University, which has been found so valuable that a second edition is now published, covering 212 large 8vo pages. It is intended for those who are not foresters or botanists, but who use woods or who desire knowledge

of their distinguishing properties. Hence it condenses the main facts and describes nearly five hundred species of timber producing trees, giving for each:

Nomenclature; Locality; Features of tree; Color, appearance or grain of wood; Weight qualities of wood; Representative uses of wood; Weight of seasoned wood in pounds per cubic foot; Modulus of elasticity; Modulus of rupture; Remarks, which latter are frequently of great interest.

It is not a book for consecutive reading, but one for reference; a copious index of 14 pages and a well digested classification, giving the engineer access to the facts which he needs to know in order to obtain the best economical results.

There are nearly 40 full page half-tone illustrations showing the tree—the foliage—and the wood in section—besides many smaller engravings through the text, which add much to the value of the book. O. C.

Fowler's Electrical Engineers' Pocket Book. Edited by William H. Fowler., M. Inst. C. E., M. I. Med. E., etc. The Scientific Publishing Co., Manchester, England. 1908. 4 by 6 ins. 679 pp., with index, many illustrations, diagrams and tables. Price, 2s. 6d.

This is an English book gotten out in cheap and popular form. Considerable space is given over to advertising, thus appealing to the commercial engineer, but introduced among the reading matter the tone of the work is thereby lowered. Many of the uses of electricity are interestingly described, as are also the principal electrical machinery. Considerable practical information regarding the operation of electrical machinery is also given. The book is a handy little volume and the data in it will be found of considerable value.

S.

Economic Zoology: An introductory text-book in zoology, with special reference to its applications in agriculture, commerce and medicine, by Herbert Osborn, M. Sc., Professor of Zoology and Entomology, Ohio State University. The Macmillan Company, New York, 1908; Cloth; 5½ by 7½ ins.; pp. 490, including ten pages of index, 269 illustrations. Price $2.00 net.

The title of this book would not at first suggest it to be one of considerable interest to engineers, yet an examination will show much that is of value, particularly in widening the understanding and giving information along the lines of present day investigations. The great extent to which animals and animal products enter into commercial transactions, in which all are more or less concerned, is reason enough for such a book as this and its presence in an engineers' library. It is a text-book for college use, but it has a value to all intelligent men who desire to know the general principles and present status of knowledge regarding the animal kingdom. The work is divided into twenty-one chapters, of which the first is an Introduction, explaining that zoology relates to animal life, and in a broader sense includes what pertains to the life of an animal, which term, by the way, is far broader and more comprehensive than many might at first suppose. The Introduction explains classification as branches, classes, order, families, genera and species; and succeeding chapters explain the Protozoa, with sub-divisions and an explanation of the economic importance of Protozoa. As the name implies, this is the first or lowest form of animal life.

Succeeding chapters describe higher forms of life, as Sponges; Worms, flat and round; Annelida, or earth worms; the Polyzoa; the Starfish; Mollusca; Crustacea; the Arachnida (scorpions, spiders, etc.); the Protracheata (or centipede). The class of Insecta is a very large group of animals in number of species, and though generally small in size, they occupy an important position in the study of zoology. A great number of these fill an important place in economics, whether as useful creatures or destructive agencies. Other chapters consider yet higher forms, as the Chordata, Vertebrata, Pisces, Amphibia, Reptilia, the Birds and Mammalia.

Economic Zoology, as the title implies, shows the value and relation to mankind of the various forms of animal life, and when one has acquired some knowledge of the scientific terms employed, it will prove to be a valuable book.

W.

ARITHMETIC OF ELECTRICAL ENGINEERING: By Whittaker. The Macmillan Co., New York. Cloth, 7½ by 5 ins.; pp. 159. Price 50 cents.

The book contains 72 worked examples and 300 exercises involving direct currents. The exercises are grouped under the following headings, each of which constitutes a chapter: Units of Length and Mass, Conductors and Resistance, Ohm's Law, Work and Power, Divided Circuits, Arrangement of Cells, Heating Effects of a Current, Electrochemistry, Condensers and Capacity, Transmission and Distribution, Magnetic Quantities, Electromagnetism, and Galvanometers, Magnetization of Iron and Magnetic Circuits, Generators and Motors. The exercises are well graded, and the definitions of the terms are clear and concise. The theory involved is given in connection with each group of problems, and all formulas are derived from the definitions and theory.

The book ought to be valuable to students of electrical engineering.

F. A. R.

PRACTICAL IRRIGATION: Its Value and Cost, with tables of comparative cost, relative soil production, reservoir dimensions and capacities, and other data of value to the practical farmer. By Aug. J. Bowie, Jr. McGraw Publishing Co., New York. Cloth, 6 by 9½ ins., pp. 232, 53 figures, LXXIV tables. Price $3.00.

The author of the book is well known to the profession from his book on Hydraulic Mining, written some twenty-five years ago, and which is still a standard. He has also written other fragmentary matter and has been employed as an expert in irrigation investigations by the Government, so the book may be said to be the work of a thoroughly competent man. The title, with its sub sentences, quite accurately describes the contents of the book. It should be of great value to engineers residing in states where irrigation is practiced, and nearly every page can be read profitably by farmers, whom the author would have us think were in his mind when he prepared the work. One cannot help but smile as the image of the farmer who could digest some of the mathematical work, rises before his mind.

The reviewer of this work was employed for many years on irrigation work and so feels that he can consistently recommend it very highly, as filling a gap in irrigation literature. It stands in relation to some of the standard treatises, as Goodell's "Water Works for Small Cities and Towns" stands to some of the heavier and more standard works on water supply as he takes up points of immense importance, interesting to the investor and manager of irrigation enterprises, rather than to the strictly technical engineer. The trend in modern engineering literature is towards economic engineering rather than solely to the engineer as a surveyor and designer. For men whose inclinations are towards the business side, the book will appeal.

McC.

HYDRAULICS OF RIVERS, WEIRS AND SLUICES: By David A. Molitor, C. E., Mem. Am. Soc. C. E. New York, John Wiley & Sons; 1908; 6 by 9 ins.; 135 pp. with index; many illustrations and tables; Cloth. Price $2.00.

This new treatise on hydraulics gives "The derivation of new and more accurate formulae, for discharge through rivers and canals obstructed by weirs, sluices, etc., according to the principles of Gustav Ritter von Wex." The book is dedicated to the memory of Hofrat Gustav Ritter von Wex, who was Chief Director of the Danube River Regulation and Improvement at Vienna; born in 1811 and died September 26th, 1892. Hofrat von Wex is regarded as a high authority on hydraulic matters and is the author of "Hydrodynamik," a book in which he advanced some new views on hydraulics which

are worthy of careful study by engineers engaged in this line of work, at this time when water-power development is attracting so much attention.

There is an Introduction, with definitions and explanations of terms employed, followed by Chap. I, Fundamental Equations; Chap. II, Complete Overfall Weirs; Chap. III, Incomplete Overfall Weirs; Chap. IV, Sluice Weirs and Sluice Gates; Chap. V, Backwater Conditions; Chap. VI, Flow in Rivers and Canals; and Chap. VII, Empiric Coefficients. Then follows Appendix A," a collection of weir formulae proposed by different authors for complete and incomplete overfalls"; also, Appendix B, "A Novel Hydraulic Problem—the Flow over a Flight of Panama Canal Locks." This is in the line of Mr. Molitor's work as Designing Engineer, Isthmian Canal Commission. Finally, Appendix C gives "A tabulation of the new formulae arranged for ready reference."

The text is clearly written, the formulae and how they are derived are well expressed, and altogether the book is a valuable one for hydraulic engineers, though the author frankly confesses that further experimentation and study of results are necessary to settle some uncertain points for determining the value of some constants in the formulae presented.

The topography is all that could be asked, and is up to the usual high standard of the Wiley publications. W.

Road Preservation and Dust Prevention: By William Pierson Judson, M. Am. Soc. C. E., M. Inst. C. E. New York, Engineering News Publishing Co. Cloth, 6 by 9 ins.; pp. 144; 16 illustrations. Price $1.50 net.

The damage done to macadam roads by fast traveling automobiles is causing alarm all over the world. The automobile being here to stay necessitates a study on the part of highway and park engineers of new methods of road construction as well as methods for road preservation.

This book is needed and well fills the need. It contains as full accounts as it is possible to obtain, of all the methods so far tried in all countries to keep down dust and retard disintegration of road surfaces. Incidentally it touches upon improved methods of making roads that are better able to stand fast traveling than are the best macadam roads.

As collection of reliable data on methods and materials hardly passed the preliminary advertising circular stage this book is a welcome addition to the library of the highway engineer.

Practical Reinforced Concrete Standards: For the design of reinforced concrete buildings. By H. B. Andrews, M. Am. Soc. C. E. Simpson Bros. Corporation, Boston. 1908. Cloth; 8 by 11 ins.; pp. 46, mostly tables and diagrams. Price $2.00.

The literature of reinforced concrete threatens to become as voluminous as works discussing the tariff and currency questions, so that now the first question that the reviewer asks is "Why did the author write this book?" The answer to the question with respect to the book here under review is satisfactory. The book was prepared by a busy engineer to help him in his daily work. That much is manifest from even a cursory examination of its pages. It has evidently been printed because the author hoped it would prove as useful to others as it had proven to himself.

It is an excellent working handbook of reinforced concrete design. In a few pages the author presents his theory of T beams and the results check with standard theories and formulas. The subject of shear, or of internal stresses in beams, is now a burning one and he gives a very simple method for determining when the stress in the concrete reaches the point where stirrups must be used. Then follows a diagram to determine the thickness of slab and area of slab reinforcement required for different spans and loadings.

Then follows a number of pages of tables of standard sized T beams and these tables contain bending moment, area of steel, bill of material of steel, area of concrete, etc. The method of use is simple. Having a certain span

given with the superimposed loading first take from the slab diagram the thickness of the slab and area of steel. Having this information and the span of the supporting beam the next diagram gives the bending moment for different spans with loading per lineal foot. All that is then required is to look in the beam tables and select a beam having a slab of the proper thickness and designed for the given bending moment. On the same line is given all the necessary information and reference is made to illustrations of the standard beams so that the designer is not left to guess at anything.

For the man who has only occasional work to do as well as the man who is working on reinforced concrete designing every day, this book can be recommended highly. It contains useful information on columns, foundations, footings, etc., so that the field of ordinary building construction in reinforced concrete is pretty well covered. It can be recommended. E. McC.

Analysis of Elastic Arches: By Joseph W. Balet, Consulting Engineer. Engineering News Pub. Co., New York. 1908. Cloth, 9½ by 6 ins.; pp 316, including index; 24 figures. $3.00 net.

The author has divided this work into ten chapters, with an introduction and an appendix, chapters seven to ten comprising the appendix.

In Chapter I, the author discusses the various forces in the arch and is in the nature of an introduction to the subject as a whole. Chap. II takes up special combinations of forces which are demonstrated by a graphical computation of the stresses in three hinged arches of various forms, while Chap. III is similar to Chap. II, dealing with two hinged arches of various forms, as relating to the displacement theory and of the elastic theory. Chap. IV is devoted to the application of the elastic theory to hingeless or monolithic arches.

Chap. V takes up the distribution of stresses in arch ribs of concrete, stone and steel, and contains formulas for both column and slab design, as well and is more in the form of memorandum than a treatise on these subjects. Chap. VI is similar to Chap V, and deals with wind and other forces on the arch, and of the good and bad qualities of various types of arches.

The remaining chapters are in the form of an appendix, and are devoted to algebraic deductions of the elastic theory as applied to arches, the last chapter taking up the displacement theory. The spirit of the book is good, but it is not evident that it holds very many advantages over other works on the same subject, as a book of ready reference, although the author has gone into the subject very thoroughly and has put in a great deal of time and labor in the preparation of the volume.

The only point that is open to criticism, is that most of the diagrams are crowded and altogether too small to be clear or easy to follow, and some of the inserts are poorly incorporated into the volume. The work is one of value to the student or for reference, but could hardly be said to be a book available to have at hand, for immediate design. G. E. T.

Highway Engineering: By Chas. E. Morrison, A. M., C. E., Tutor in Civil Engineering, Columbia University. New York, John Wiley & Sons. Cloth, 6 by 9 ins.; pp. 315; 60 figures. $2.50.

This book is best presented by the following quotations from the Preface. "The following pages were prepared for the second year students of the department of civil engineering at Columbia University with a view to furnishing a text in which the fundamentals of the subject should not be buried in a mass of details, such as is frequently found to be the case in works of a similar character. This book is therefore not a reference work, but rather one in which it has been the endeavor to outline and emphasize these basic principles which are essential to good highways."

The Preface goes on further to acknowledge help received from Government and State Reports, etc. The reviewer believes the author has performed very well the task set for himself and as a text book it is very good.

It has the dogmatism seemingly deemed necessary for Sophomore text books, but is decidedly weak in lacking a bibliography on the subject of roads and highways. While it does avoid detail at the same time the student should not be left to imagine that within its covers lies all that is known on the subject, nor that the teacher-author has in all cases made the wisest selection of matter. A good text book should be also a reference book for future years and to place at the close of the chapters lists of good works is today a very essential detail that no author should neglect.

The reviewer somehow thinks that he prefers Baker's work or Bryne's Highway Construction, faulty and deficient as is the last edition. The book therefore has its place as a college text book and hardly suffices for the needs of the practitioner, except it be for the purpose of instructing officials.

E. McC.

ELEVATOR SERVICE: By R. P. Bolton, Mem. A. S. M. E. Published by the author, No. 527 Fifth Ave., New York. 1908. Cloth bound, 7½ by 11 ins., 69 pages, numerous tables, and 11 figures, including a large folding diagram. Price $5.00.

This book contains eleven chapters concerning the Problem of Vertical Transportation; Operating Conditions; Passengers and Operators; Rating the Work of the Elevator; Computing the Average Work; Express Service; Shape and Size of the Car; Load and Speed Combinations; the Building and its Proportionate Service; with an explanation of the folding diagram and examples for its use, and finally a chapter of definitions. It should be noted that in this book the calculations, diagrams, etc., relate to Elevator Service particularly for high office buildings. For department stores, hotels, and flat buildings, the conditions of service, travel, etc., are different and should be considered in making calculations as to the number of elevators needed, their speed, service, etc.

The function of the elevator involves not only the lessening of human effort by the lifting (or lowering) of human freight, but the shortening of time for such transit. To get the advantage of this feature, passenger elevators must move rapidly between stops and not make too many stops in any one run, otherwise the service is "too slow" and there will be complaints from the tenants of the building. The author of this book, who has had wide experience in this subject, advances the proposition that the most efficient service is to be had from the elevators when the number of passengers and stops in any one complete up and down or round trip, is 0.8 of the number of floors to be served. Applying this rule to the Monadnock Building, which has 16 (and 17) floors, the most efficient service would be when there were not over seven passengers (and stops) in each direction. This is assuming that each passenger will require his own stop. As a matter of fact, it is not often that this condition occurs as there is seldom a trip with a number of passengers, that two or more do not leave the car at the same floor. However, in working out his theory the author has prepared some interesting charts and diagrams in illustration. Some of the tables are of interest, as showing the density of population in buildings of various kinds; that is, the number of square feet of floor space allowed per tenant, which varies with the character and use of the building. This may be as low as 80 sq. ft. per tenant in some old ten family "old law tenements" or may be as much as 365 sq. ft. per tenant, in high grade first class apartment hotels.

In office buildings, such as the Monadnock, the allowance of space would probably average about 150 sq. ft. per occupant. On the basis of 16 floors of 26,000 sq. ft. each and at 150 sq. ft. per occupant, there might be a population in that building of 2,773, but as a matter of fact the population of the Monadnock is nearer 4,000. The Monadnock Building is provided with 16 elevators, each of 33 sq. ft. area, and with a carrying capacity, according to this author, of about 14 persons. As a matter of fact, from exigencies of operation sometimes some two or three elevators are not operated, and it is only at special hours that the elevators are fully loaded. By actual court,

in an ordinary day, the 16 elevators in the Monadnock have carried 30,000 persons. These figures are given here that those interested may make a comparison with the data in Mr. Bolton's book. There may be some architects, whose experience will lead them to differ from the deductions from the data and figures offered by the author. But the book is valuable in presenting such data as is herein, and a study of the book should be of value to anyone concerned with the question of elevator service in buildings. W.

RAILWAY TRACK AND TRACK WORK: By E. E. Russell Tratman, A. M., Am. Soc. C. E., M.W.S.E. Engineering News Publishing Co., New York. 1908. 3rd Ed. Cloth; 6 by 9 ins.; pp. 520; 232 illustrations, 44 Tables and an Appendix of Statistics of Standard Track Construction on American Railways. $3.50 net.

Someone has said that the location of a railroad is its constitution. If this is true, then the track-work of that road is its daily diet. Mr. Tratman, in the opening paragraph of the preface of the third edition of his book, calls attention to the meager literature existing on the subject of track work. We have not, as engineers, studied the subject thoroughly enough to enable us to write so we would be willing to sign our names to what we wrote.

Last year some of us were compelled to economize and some thought best to find out what maintenance of roadway was costing and where economy really lay. Some trunk lines having excellent track do not know what it costs them, much less whether better track could not be had for less money.

The Board of Research, which was established by the Baltimore & Ohio Railroad last fall for the purpose of finding out what ballast was most economical for them for each part of their line, is a wise, broad-gauge innovation. Did we build bridges as blindly as we build and maintain track, one-half of us would be in the asylum and the other half in the penitentiary.

Mr. Tratman published his first edition in 1897. The second edition appeared three years later. The third edition recently issued is added proof of a demand for such a book. The new edition is one-fourth longer than the first one, and seems practically re-written. The binding is durable and suitable. The paper and press-work are excellent. The type is a little small for the circumstances under which it must be read, but a larger type would have made the book too bulky, and might have discouraged trackmen. It appears to be well indexed—an invaluable aid to the use of such books. The cuts are numerous and aid the text in a way most desirable to the non-technical reader. "Pictures are quicker read than print."

In adding the one-hundred pages to the third edition as compared with the first one, the author has increased the number of the chapters by four. He had added a chapter on "Signals" and "Interlocking" and also a chapter on "Electric Railways." These subjects very properly belong today to a complete work on the subject and illustrate the broadening of the railroad problem. The former chapter on bridge floors and grade crossings, as well as the former chapter on track laying and ballasting, are each divided into two chapters in this new edition. The new divisions seem the more natural ones.

This edition of the book shows an advance in every way over preceding editions. From its first appearance the book has been useful, for it was studiously and thoughtfully written. The present edition will take a still higher place in the literature of track work. W. B.

LIBRARY NOTES.

The Library Committee wishes to express thanks for donations to the library. Back numbers of periodicals are desirable for exchange and in completing valuable volumes for our files.

Since the issue of the JOURNAL for April, 1908, we have the pleasure to report the following additions to the library and gifts from donors named:

MISCELLANEOUS GIFTS.

Hill Publishing Co., New York. "Metallurgy of Iron and Steel," by Stoughton, 1908. Cloth.
"Gas Power," by F. E. Junge, 1908. Cloth.

E. I. du Pont de Nemours Powder Co., Wilmington, Del. "Useful Information for Practical Men," 1908. Leather.

Dr. Alford Beirly, Chicago. "A New Harbor for Chicago." Pam.

Maj. C. S. Riche, Davenport, Iowa. "The Further Improvement of our Inland Waterways," 1908. Pam.

Dr. George A. Soper, New York. "The Pollution of New York Harbor." Pam.

E. E. R. Tratman, M. W. S. E., Chicago.
"Preservation of Timber," by S. M. Rowe. Leather.
"Cost of Car Repairs," by H. M. Perry. Leather.
"Handbook of Engineering," by H. C. Tulley. Leather.
"Annual Report of the Dept. of Public Works, Chicago," 1906. Cloth.
"How to Handle Freight," by R. C. Richards. Cloth.
"Locomotive Breakdowns," by G. L. Fowler. Cloth.
"19th Annual Report Statistics of Railways in the U. S." 1906. Cloth
"Bulletins Amer. Ry. Engr'g and M. of W. Assc'n." 8 Pams.
"Bulletins, 20 and 21, U. of I. (Engr'g. Experiment Sta.)" 2 Pams.
"Journal Railway Signal Assc'n," May, 1908. Pam.
"Official Circular, Tramways and Light Ry's Assc'n," London. Pam.
"Advance papers, British Institution of Mechanical Engineers." Pam.
"Papers on the Steam Turbine," by C. A. Parsons. Pams.
"Papers relating to International Congress of Tramways." Pams.
"Report of the General Manager of Railways for 1907." 2 Pams.
"Journal, Railway Signal Association," No. 3, 1908. Pam.
"Stope Drills," by Prof. J. Orr—Reprinted from Proc. of Transvaal Inst. of Mech. Engrs. Jan., 1908. Pam.
"Int'l Congress of St. Rys. and Light Rys.," Munich. Sept., 1908. Pam.
"Motor Omnibuses in Europe," by M. Manclere. Pam.
"Steam Cars and Light Locomotives for Local Railways," by von Littrow. Pam.
"Locomotives for Narrow Gauge Railways," by M. H. Heimpel. Pam.
"Report of Chief Commissioner, New South Wales, on Government Railways and Tramways," June, 1908. Pam.
"Report, Committee of National Electric Light Assc'n on Gas Engines," May, 1908. Pam.

American Gas Institute, New York. "Proc. American Gas Institute," Vol. II, 1907. Cloth.

David Williams Co., New York. "The Blast Furnace and the Manufacture of Pig Iron," by Robert Forsythe, 1908. Cloth.
"The Iron Age Directory," 1908. Cloth.

Public Library, Lynn, Mass. "45th Annual Report of Trustees for 1907. Pams.
"Books on Electricity in the Public Library of Lynn," Mar. 1908. Pam.

George Weston, M. W. S. E., Chicago. "Report on the Union Elevated R. R. Loop," April, 1908. Pam.

State Commissioner of Public Roads, Trenton, N. J. "14th Annual Report for 1907." Cloth.

Slason Thompson, Bureau of Railway News. "Cost, Capitalization and Estimated Value of American Railways." Cloth.

The Macmillan Co., New York. "Principles of Direct Current Electrical Engineering," by James R. Barr, 1908. Cloth.
"Elementary Dynamics for Students of Engineering," Ervin S. Ferry; 1908. Cl.
"Elements of Physics: v. 2, Electricity and Magnetism," by E. L. Nichols and W. S. Franklin, 1907. Cl.
"Economic Zoology," by Herbert Osborn. 1908. Cl.

Iowa Geological Survey, Des Moines, Iowa. "Vol. XVII, Annual Report," 1906. Cloth.

Otis F. Clapp, City Engineer, Providence, R. I. "Annual Report of City Engineer for 1907." Pam.

Michigan Highway Commission. "First Biennial Report of State Commissioner 1905-6." Pam.

New Orleans Sewerage and Water Board. "16th semi-annual report," Dec. 31, 1907. Pam.

John Lyle Harrington, Kansas City, Mo. "The Necessity for Individual Engineering Libraries and for continuing study after graduation, by J. L. Harrington," 1908. Pam.

E. P. Dutton & Co., New York. "Municipal Ownership," by Leonard Darwin, 1907. Cloth.

Mass. Highway Commission. Reports for 1893, 1897, 1901, 1907, 1908. 5 Vols. Cloth.

Engineering News Publishing Co., New York. "Design of Typical Steel Railway Bridges," by W. Chase Thomson, 1908. Cloth.
"Road Preservation and Dust Prevention," by W. P. Judson, 1908. Cl.
"Railway Track and Track Work," by E. E. R. Tratman, 1908. Cl.
"Concrete System," by Frank B. Gilbreth. Flex. leather.

American Inst. of Mining Engineers, New York, Trans. 1907; Vol. 338. Pam.

T. J. Dalzell, Commissioner of Mines, Colo. "Report of the State Bureau of Mines, Colo." 1905-1906.

Metropolitan Water and Sewerage Board, Boston. "7th Annual Report," 1907. Cloth.

Cement Era Publishing Co., Chicago. "Reinforced Concrete, A Manual of Practice," by Ernest McCullough. 1908. Cloth.

Edward A. Bond, Chairman, Advisory Board of Consulting Engineers, New York. "Report upon work on Barge Canal for 1907. Pam.

Boston Manufacturers Mutual Fire Insurance Co., Boston; "Report No. 5, Slow Burning of Mill Construction." Pam.

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MEMBERSHIP

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Bixby, W. H., 428 Custom House, St. Louis, Mo.
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Chandler, Geo. M., Supt. L. W. Riddle (Concrete Const.), First Nat'l Bank Bldg., Chicago.
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Goldman, Henry, c/o Isthmian Canal Comm., Culebra, C. Z., Panama.
Kreisinger, H., c/o U. S. Geol. Survey, 40th and Butler Sts., Pittsburgh, Pa.

Lamphere, F. E., 3751 Ellis Ave., Chicago.
Lowe, Jesse, Beardstown, Ill.
Marston, W. S., 911 N. Prairie Ave., Austin, Chicago.
Melendy, R. P., 21 Cumberland St., Boston, Mass.
Otis, H. B., 1200 Fort Dearborn Bldg., Chicago.
Pierce, S. L., 1109 N. Halsted St., Chicago.
Place, Floyd W., Lock 14, Tidewater, Ala.
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Rust, Henry A., 606 Great Northern Bldg., Chicago.
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Sawyer, Geo. L., 410 Lindelle Blk., Spokane, Wash.
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Stimmel, Charles H., Kenton, Ohio.
Tedman, H. A., 321 Sixth Ave., Cedar Rapids, Iowa.
Thomas, Homer, c/o Trussed Concrete Steel Co., Bedford Bldg., Chicago.
Watkans, Frederick A., 24 Ruthren Pl., Summit, N. J.
Wilson, F. N., 320 E. 41st St., Chicago.
Wood, C. M., Ch. Engr., Kansas Gas & Cement Co., Strong City, Kans.
Wright, Joseph, c/o U. S. R. S., Dodson, Mont.

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Henry, Smith T., Old Colony Bldg., Chicago .... Associate
Ryan, Laurence P., 1558 Kenmore Ave., Chicago .... Associate
Six, William L., 256 Winthrop Ave., Chicago .... Active

Deceased Member:

E. H. Beckler .... August 26, 1908

WESTERN SOCIETY OF ENGINEERS

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The above named officers of the Society and three past presidents, constitute its Board of Direction.

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THE ELECTRICAL SECTION

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O. E. OSTHOFF...1 year
K. B. MILLER...2 years
E. N. Lake...3 years
Members of Executive Committee.

MEETINGS

Regular Meeting—1st Wednesday evening of each month except January July and August.

Extra Meeting—3rd Wednesday evening of each month except July and August.

Electrical Section—D. W. Roper, Chairman, generally the 2d Friday of the month, October to May, inclusive.

Board of Direction—The Tuesday preceding the 1st Wednesday of each month.

NOTICE

From the dues of each member, $2 00 is set aside as a subscription to the JOURNAL.


Reception and Reading Room—to the East; Entrance at Righthand, Assembly Room to the Left


Part of Reception Room and Secretary's Office—to the West; Assembly Room at Righthand

Assembly Room, Speakers Stand at North end

A Corner of Reading Room, and the Library beyond the arched opening

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THE ANALYSIS OF AN HYDRO-ELECTRIC PROJECT

H. VON SCHON, M.W.S.E.

Presented September 2, 1908.

The possession of hydro-electric power, of electric energy of hydro power source, is the nearest approach to the realization of the promise of Alladin's lamp yet vouchsafed to the human race. The captive or liberated current is ready to sustain and comfort human existence as no other agency can, while the everflowing waters return year after year ready to renew their allegience to this service of mankind. Nor need they fear any economical rival of whatever source at the present as well as the likely distant future. He who owns a coal, oil or gas deposit is said to be possessed of a valuable treasure, but what is the fortune of him who controls a water power of like inherent value?

Coal oil and gas are brought forth, perform their useful work and are no more, their former lodgment place, a void. Water, however, comes, works and goes, to come again and again, without man's influence or design, leaving no waste but being of infinite existence, duration and effect. Open a fuel deposit and its exhaustion is but a question of time, harness a water power and you have merely started a perpetual power source. The one is exhaustible, measureable, finite, the other everlasting.

If this be true, and your criticism to the contrary is confidently challenged, is it any wonder that these opportunities of water powers are being sought for, all over the universe with feverish activity, and if so, why has it been reserved to this generation to recognize these facts? Water power has been impressed for useful work from the beginning of human existence but the advent of electric energy, and the union of these two, hydro-electric, has given this old-time power source, a new sphere in which its import has gained for it the first and foremost place among all power sources. And this is of comparatively recent advent, so recent that as a phenomenon which enters into the daily life of every member of civilized mankind, none is less understood, none is shrouded in greater mystery.

The millwright of old knew well how to utilize water power for his particular purposes; he found the suitable mill-site and there

developed the needed power. Not so in our day; here is a place where current is wanted, where is the water power which will produce it? A community needs lights and power and where is the water power source? Whether at its door or one hundred miles distant, it matters not, somewhere the supply can be found.

The analysis of the hydro-electric power project should be initiated by that of the market for its product. Name me a city in these United States which does not enjoy the advantages of efficient and economical power current and I can lead you to the water power from which it can secure both. The present power consumption in the United States for industrial and for public utility services aggregate 15,000,000 H. P. of which water power is credited with 2,000,000; the undeveloped water power possibilities of this country approximate 10,000,000 H. P. under the present conditions of flow, that is with ten times of the normal flow in our rivers going to waste during flood periods, it could be more than tripled by the economically practical conservation of the now wasting and destruction spreading flood waters. On the large majority of our rivers the high monthly flow is ten times that of the low and on many a hundred, and when the availability of water power source is claimed for all present purposes and more, it is based upon the conserved energy. Many an apparent water power opportunity must be classed as impracticable to-day because there is too much water at times, the flood flow eliminates the practicable normal flow development program while its reasonable conservation would render it of the greatest power opportunity values. It has been established by exhaustive Government investigations that the practicable water power capacity of the Ohio river and its chief tributaries at present, is less than one million horse power and that conservation of the flood flow, or of a considerable portion of it, may be secured at the cost of an investment for storage reservoirs and the necessary controlling works of about one hundred and twenty-five millions of dollars, and that such program would prevent many of the disastrous floods, would greatly reduce the cost of the proposed navigation works and incidentally would increase the available water power capacities to five million horse power; a tax of less than one dollar per horse power annually, would meet the interest on such an investment. The same may be claimed for other river systems in this country, yes for many others.

The power market is everywhere, the market for electric current, not only for lighting but for power service. The mechanical mill and shop drive is doomed to give place to the individual machine electric motor application. As the mill which of old used to locate at the water power site now ignores the locus of the power source and secures the manifold other advantages due to the proximity of the raw material or the market for its output, of labor conditions, centralization of manufacturing lines, and conveniences of maintenance and operation, so do factories and shops begin to realize the

greater advantage of planing their operating processes independent of power plant proximity, line shafts, pulleys and belts, by substituting the small flexible wire as the power conductor, avoiding the noise and dirt and dust and securing the greatest of all advantages, economy of power cost and the advantage of paying only, for power work actually done. Where and what is the industry using power which cannot secure these advantages of manufacturing process, increase and betterment of output, healthful and cheerful operating conditions and finally, a saving in their power cost so great that it can well afford to assign boilers and engines to the scrap pile or store them as historic relics of bygone days, if they will change the mechanical to electric drives? And where and what is the business undertaking or the public or private establishment which cannot utilize to economical advantage, electric power current in one form or another?

That the analysis of the current market is an engineering topic will clearly appear during its discussion.

The purpose is to first determine whether the necessary franchise to enter the market and sell the current can be obtained and secondly, to ascertain the existing power and current consumption and its probable increase under favorable conditions growing out of efficient current service at a saving over other available power sources. The program consists in inventoring every existing power plant of whatever source, central, municipal or of factories and shops, noting the character, age and condition of the generating equipment, the operating methods, capacities, fuel supply conditions, duration of services, and load factors. This covers the existing possible motor loads. The lighting business is likewise canvassed ascertaining the extent and character of the current distribution and equipment system, the number and capacities of services for public, commercial and domestic lighting and the rates paid. In no case, however, will it prove practicable to ascertain much of value regarding the cost of the power output because there is no subject of which the manufacturer or operator has less reliable knowledge and conclusive data. The cost of the plant, the annual amount paid for fuel, oil, waste and operating, may all be on the books but the items which make up the annual cost of maintenence, depreciation, efficiency of boiler, engine and drive output at various load factors are not available in such a manner that these all important features can be even estimated.

The most complete recent investigation of the cost of power from steam plants with coal, gas or oil fuels, and of the continuous output at various load factors, have been concluded during the past year by the Hydro-electric Power Commission of Ontario, Canada. The territory covered by this inquiry compares well, industrially speaking, with any in the United States, with the exception of New England; the cost of plants and of operating will be lower than those for like plants on this side and the application of these data for this discussion will therefore err on the side of safety. The cost of steam

plants includes that of boilers and piping, engines of simple non-condensing type up to 50 H. P. rating and of compound condensing for larger capacities, of installation of the engine and the accessories, engine foundation, boiler setting and chimney, building, coal storage and land. The loss from B. H. P. to the main mechanical drive or belt driven generator is taken at 10% and the resulting cost is for the mechanical or electric horse power delivered to the factory or shop; the further loss from main drive to individual machine or motor being indeterminable for general treatment.

TABLE I, COST OF POWER PLANTS PER HORSE POWER.

Horse power	10	30	50	100	300	500
Steam	$132.00	$130.00	$113.00	$105.00	$80.00	$73.00
Prod. gas .	204.00	110.00	100.00	90.00	87.00	77.00
Ill. gas ...	72.00	59.00	53.00	50.00		
Gasoline ..	80.00	60.00	58.00	50.00		
Oil	90.00	70.00	68.00	60.00		

The operating cost of plants has been compiled with an interest charge of 5%, but no charge has been made for water; surface condensers have been assumed and the working cost has been based on steady loads and efficient operation; if the load fluctuates, fuel consumption and cost would increase above that herein stated. Depreciation of equipment is rated at 6%, of buildings at 2%, insurance at 1%, taxes 1½%, bituminous coal at $3.25 per short ton, anthracite for producer gas plant at $5.00 per ton, gasoline at 20 cents, and oil at 16 cents per gallon, illuminating gas at 75 cents and natural gas at 20 cents per 1,000 cub. ft. The load factor is taken at 75% of the rated B. H. P. engine capacity; the cost is given for 6,600 and 3,000 hours per year operation in dollars per year and in cents per horse power hour.

Applying these cost and operating estimates to the inventory of power plants in the market under investigation, some conclusions can be drawn as to the power rate which can secure this business. Power current is sold at a flat rate per H. P. year or at a meter rate per kw. hour. Considering the case of a customer operating a 300 H. P. steam plant operating 10 hours per day and ascertaining the mode of power application to the individual machines, as well as the probable working load factor, that is the actual time, during the day, the tools or machines are running, the above rated horse power year cost of $46.00 will have to be increased by probably not less than 10% for the loss in taking the power from the main drive to the individual machines and another 10% for the non-operating period of the machine, which would bring the working power cost to $55.00; this customer should be interested by a $35.00 or $40.00 H. P. year rate, or still more, by a meter rate of 1¼ cents per kw. hour, which would make his power cost for a continuous 10

hour operation of 308 days $38.50; as a matter of fact that particular motor would serve current only for part, say 75% of that time and the annual power cost to operate that machine would stand the customer at $28.87 probably, just about half of what it costs him with his steam plant. Or taking a machine shop with a 50 H. P. steam plant operating 10 hours per day, the power cost given in Table 2 is $89.00, and it will be considerably higher with losses in sub-drives and idle tools; a rate of 2½ cents per kw. would make his continuous power $77.00, and 75% of that, representing probably the actual working load, would be $57.75, also about half of what the steam power costs.

TABLE 2, OPERATING COST PER HORSE POWER.

Horse Power		10	30	50	100	300	500
Steam	6600 hs	$353.00	$194.00	$167.00	$120.00	$85.00	$73.00
		5.35	3.00	2.53	1.80	1.30	1.10
	3000 hs.	180.00	103.00	89.00	74.00	46.00	41.00
		6.00	3.40	2.96	2.43	1.53	1.36
Nat. Gas	6600 hs	68.00	47.00	40.00	36.00	32.00	32.00
		1.30	0.70	0.60	0.55	0.50	0.50
	3000 hs.	38.00	27.00	24.00	21.00	19.00	19.00
		1.26	0.90	0.80	0.70	0.63	0.63
Prod. Gas	6600 hs	152.00	87.00	71.00	62.00	53.00	49.00
		2.45	1.30	1.10	0.90	0.80	0.75
	3000 hs	92.00	52.00	43.00	38.00	34.00	30.00
		3.66	1.73	1.40	1.30	1.13	1.00
Ill. Gas	6600 hs	180.00	151.00	136.00	126.00		
		2.70	2.30	2.00	1.90		
	3000 hs.	90.00	74.00	67.00	62.00		
		3.00	2.50	2.23	2.06		
Oil	6600 hs	233.00	192.00	187.00			
		3.50	2.90	2.80			
	3000 hs	115.00	94.00	92.00			
		3.50	94.00	92.00			

The preponderance of power service is of small units, of 3. 5 and 10 H. P.; the cost of the latter appears in Table 2 as $180.00 per year of 3000 hours and it may be stated as a rule that it is generally greater than this; 5 cents per kw. hour, makes the 100% load factor, 10 hour service, $154.00—75% of this is $115.00, also probably about half the actual steam power cost. Power plants using natural gas may not be so easily interested but such fuel supply is uncertain at the best; producer gas power plants are not frequently met with, and neither illuminating gas nor oil secures any considerable reduction in the operating cost. Tables 3 and 4 bring the cost and rate topic

down to their practical application in analyzing the former and adapting the latter. Table 3 gives the kw. rate, which is equivalent to the cost of steam power applied to the machine, the working power, the loss from the main to sub-drives is taken at 10% and that of the idle machine likewise; the rate is in cents.

Table 4 gives the fuel consumption of all kinds per h. p. hour, and year, and from this the proper corrections can be made for fuel costs, which differ from those given in Table 1, as assumed for operating costs, quoted in Table 2.

Table 5 gives correction to steam power cost for 10 cents difference in coal cost above or less $3.25 per ton.

TABLE 3, KILOWATT HOUR RATES EQUIVALENT TO STEAM POWER COST.

Horse power		10	30	50	100	300	500
Steam	6600 hs.	9.0c	4.8c	4.1c	3.0c	2.1c	1.8c
	3000 hs.	9.9c	5.5c	4.9c	4.0c	2.5c	2.2c
Producer Gas	6600 hs.	3.8c	2.1c	1.7c	1.5c	1.3c	1.2c
	3000 hs.	5.0c	2.8c	2.3c	2.1c	1.9c	1.6c
Natural Gas	6600 hs.	1.7c	1.2c	1.0c	0.9c	0.8c	0.7c
	3000 hs.	2.1c	1.5c	1.3c	1.1c	1.0c	1.0c
Illuminating Gas	6600 hs.	4.5c	3.8c	3.3c	3.1c		
	3000 hs.	4.9c	4.1c	3.6c	3.4c		
Oil	6600 hs.	6.0c	4.8c	4.5c			
	3000 hs.	6.3c	5.2c	5.0c			

One tenth of a cent per Kilowatt hour equals per working horse power per year: of 6600 hs. . . . . $4.92; of 3000 hs. 2.24

TABLR 4, FUEL CONSUMPTION PER WORKING HORSE POWER YEAR AT 75% OF RATED CAPACITIES.

Horse Power		10	30	50	100	300	500
Steam Coal	lbs. per B. H. P. hr.	14.00	8.50	8.00	5.75	4.50	4.00
	tons " 6600 hs.	508	924	1452	2087	4900	7260
	tons " 3000 hs.	231	420	660	948	2227	3300
Prod. Gas Anth. Coal	lbs. per B. H. P. hr.	1.45	1.33	1.25	1.15	1.15	1.15
	ons " 6600 hs.	53	145	228	405	1254	2085
	ons " 3000 hs.	24	66	103	189	570	948
Ill. Gas. 600 B. t. u.	c. ft. per B. H. P. hr.	25	23	21	20	....	....
	1000 " 6600 hs.	1815	5000	7620	14520	....	....
	1000 " 3006 hs.	736	2277	3465	6600	....	....
Nat. Gas. 980 B. t. u.	c. ft. per B. H. P. hr.	16	14	13	12	12	12
	1000 " 6600 hs.	1161	3050	4720	8712	23936	43560
	1000 " 3000 hs.	528	1386	2145	3960	11880	19800
Gasoline & O	pints per B. H. P. hr.	1.3	1.1	1.1	....	.....	.....
	galls. " 6600 hs.	11800	29700	49500	....	.....	.....
	" " 3000 hs.	5360	13500	22500	...	.....	.....

TABLE 5, CORRECTIONS TO OPERATING COST OF TABLE 2 PER TEN CENTS IN PRICE OF COAL ABOVE OR LESS $3.25 PER TON.

Horse power	Working H. P. per year	Equiv. kw. hour	Hrs. per year
10	$6.27	0.1 cent	6600
	2.85	0.13 cent	3000
30	3.80	0.064 cent	6600
	1.70	0.08 cent	3000
50	3.58	0.06 cent	6600
	1.63	0.073 cent	3000
100	2.58	0.044 cent	6600
	1.17	0.05 cent	3000
300	2.02	0.034 cent	6600
	0.91	0.04 cent	3000
500	1.80	0.03 cent	6600
	0.81	0.035 cent	3000

From Tables 2 and 3 the case of a 100 H. P. 3000 hour per year steam plant is thus analyzed:

Power delivered to main drive .... 100 H. P.
Power delivered to machine .... 90 H. P.
Power actually working, 10% delay .... 81 H. P.

Cost of work, H. P. from $\dfrac{\$7,400.00}{0.81}$ is $91.36.

81 H. P. for 3000 hours is 181,278 kw. hours.

The kw. rate from $\dfrac{\$91.36}{181.278}$ is 5 cents.

At a rate of 2½ cents, the cost of 181,278 kw. is $45.32.

The electric power at this 2½ cent rate, costs the customer about half of what the steam power would amount to while all the other advantages to his mill or shop, to the arrangement of the operating process, the absence of the noise from mechanical drive, and all those already detailed are his without further cost.

If the cost of coal is $2.25 instead of $3.25 as assumed for Table 2 the cost of machine horse power is $91.36 less 1.17 × 10=$79.66 and the equivalent kw. rate is 4 cents less 0.05 × 10=3½ cents. Of a 50-horse power plant operating 3.000 hours, coal costing $3.25 the cost of machine horse power is from $\dfrac{\$80.00 \times 50}{40.5}$=$100.87

40.5 h. p. for 3.000 hours is 40.5 × 746 × 3.000=90.639 kw. hours,

the equivalent kw. hour rate being from $\dfrac{89.00 \times 50}{90{,}630} = 4.9$ cents.

With the cost of coal at \$2.00 per ton the kw. rate is from 4.9 less $0.073 \times 12.5 = 4$ cents. Or of a 300 H. P. plant operating 3,000 hours with coal at \$3.25, the cost of machine horse power is from

$$\frac{46.00 \times 300}{243} = \$56.79,$$

243 H. P. for 3,000 hours is from $243 \times 746 \times 3{,}000 = 543{,}834$ kw. hr.

and the equivalent kw. hr. rate is from $\dfrac{46.00 \times 300}{543{,}834} = 2.5$ cents,

while with coal cost at \$1.75 per ton the Kilowatt rate is from 2.5 less $0.04 \times 15 = 1.9$ cents.

In this wise each existing power should be analyzed and the case placed before its owner; it will make an impression, the customer will begin to look very seriously into this subject of power cost and if the quoted facts are corroborated by him, or nearly so, he will arrange to substitute the electric power drive just as soon as his conditions will permit him to do so, there will be no need of canvassing him any further, he will come after that electric current contract without solicitation, because he is in business to make dollars and he will not knowingly waste any. The great majority of power customers are those operating small unit plants and the small plants represent the most desirable power loads for the central plant because the load factor fluctuations of ten plants of 10 H. P. capacity will practically balance themselves; a total of 80 to 85 H. P. will probably serve them at all times during the ten hour day operating period; not so with the one 100 H. P. plant; it will run full at short periods though in the aggregate it will not consume any more current than the ten 10 H. P. plants; the full 100 H. P. output must be kept available for this customer, but the earnings from this 100 H. P. will be no more than those from the 85 H. P. kept on hand for the use of the ten small plants. And this may be still further detailed when 2, 3 and 5 H. P. plants are considered. At any rate, the small power consumer is the important factor in this market analysis and there are plenty of them in every community. The Baker, Blacksmith, Boiler maker, Bookbinder, Boot & Shoe Manufacturer, Brewery, Brickyard, Butcher and Candymaker, Carpenter shop, Carriage works, Cigar Factory and Cold Storage plant, Contractor, Cotton mill, Creamery, Drug store, Dyeing establishment, Electrotypers and Flour mills, Foundries, Furniture Shops, Grain Elevators, Harness shops, Hat makers, Jewelers; Knitting mills, Laundries and Livery stables, Machine shops, Monument works, Paperbox makers, Paper mills; Photographers, Organ & Piano Manufacturers, Planing mills;

Plumbers, Printing establishments, Railroad shops, Rope and Cord Manufacturers, Sash and Door mills, Ship yards, Saw mills, Shirt and Overall Manufacturers, Silk mills, Soap works, Steel mills, Stone Quarries, Tailoring establishments and Tanneries, Tent and Awning works, Textile mills, Wagon works and Woolen mills and many others are the industries requiring power and some of these are found in any community. In fact there is no establishment, private, public, business or manufacturing, which cannot use electric power in one way or another to economical advantage and the present day motor application reaches a great multitude of such wants for the operation of a great variety of machines.

Wherever a flexible wire can be taken, there may be the power available, whether on the ground, in the air or under the water; in the house, train, boat, or airship; no place or condition forms an impassible obstacle for the electric power current, it is simply a question of economics and they are generally assured.

This power load inquiry is the principal feature of the market analysis, the lighting load is secondary to it. No hydro-electric project should be pronounced a safe business enterprise unless the visible power load revenue will meet the charges; the night load revenue, from the lighting business, should be considered as a net surplus. The public light requirements are evident and are generally covered by a contract of some years' duration or provided for by a municipal plant; the commercial and domestic lighting business is open to competition of service, quality and rates. Small town central steam plants are generally insufficiently equipped to give proper service; they have to supply the field at rates which do not leave much, if any, margin, above the steam power cost of current production, and the advent of a hydro-electric supply will generally compel the steam power plant to buy the hydro-electric current or sell the steam plant at the best obtainable price. Competition with the hydro-electric output is out of the question, no matter how low the cost of coal. A detail canvass of the public and private establishments is the foundation of the lighting business analysis; a plan of the town with every house located on it, is indispensable for this purpose. Small dwellings of 4 to 6 rooms are generally wired for two lights per room, those of 8 to 12 rooms will average three per room and the more pretentious homes up to five lights per room; these are generally all of 16 candle power. The yearly light period from dusk to ten o'clock at night, aggregates 800 hours; a 16 c. p. incandescent filament lamp requires 55 watts and its normal annual consumption is therefore about 4.5 kw. hrs. The lighting load which can be obtained in a community is difficult to estimate, the volume of commercial and store lighting depends very largely upon the business methods employed to secure it and of course upon the rates. One well lighted store in a block will soon set up a rivalry among the remainder to out-shine it; it is a lucrative current business which can be had in any community, while

residence lighting is more largely based upon the standards of necessities. At any rate, as already stated, the lighting business should not be considered in estimating the available revenue, as the probable income from the power load should suffice to cover all the charges.

The market investigation being completed the power opportunity itself is examined for the purpose of determining the feasibility of development from the physical and commercial point of view. Restrictions of and to usage, is the first topic; Federal and State control should be clearly defined and the required concessions obtained by legislation. Many of the streams are under the control of the U. S. War Department because navigation works have been erected or are contemplated and authorized by Congressional acts. No water power development can be created on these within the reach over which such authority extends, without license or lease from the department. But permission may be secured for developments which do not interfere with the unobstructed navigation program which is outlined for them. Leases may be obtained for the development of the flow over the Government navigation dams, the department reserving approval of the contemplated development program and of plans of the work; an annual charge is made for the occupancy of Government land and for the power use of the water. In many states, canalization and irrigation statutes limit the use of the stream for power purposes, and in nearly all states, the county authorities exercise supervision over dam structures and diversion projects. The rights of up and down stream riparian holdings should also be carefully examined and communities often control a portion of the flow for supply purposes. This investigation of control and rights is clearly within the Engineer's scope as the substance in all such questions is one of hydraulic data and facts.

The required flowage area is the next topic; what acreage will be overflowed can be determined only from a detailed survey, which can not be entered upon until the development site, operating fall and the corresponding flood flow height are decided upon. The development site is generally predetermined or will be readily recognizable after a reconnaissance of the stream in the vicinity of the proposed location; the available fall is found from level lines run up and down stream and these should always be verified by check lines. The accepted fall fixes the theoretical horizontal plane of the upper pool or pond but in no wise the flowage area; a proper allowance must be made for the back swell in this pond; its up stream terminal must be determined and the flood rise should be added to this. The resulting elevation is that of the flowage area which is outlined by a transit survey of the established benches and is tied to known land subdivision bounds.

In many hydro-electric projects with which the author has been connected, the investigation has ended at this stage because the flowage area included public improvements, railroads, highways,

cemeteries, etc., which could not be interfered with, or because private properties of prohibitive values fell within it. It is a pretty safe, though arbitrary, rule that the cost of flowage rights and safeguards should not exceed the aggregate of $25.00 per H. P. delivered at the market. In many such ventures of which the author has knowledge, detail plans and specifications were prepared before the acreage and therefore the cost of the flowage area was even known and in some cases plants have been constructed and operated and overflowed lands settled for in and out of court afterwards. As to which is the business program certainly needs no argument.

The Power Output is the next topic and as the available fall has been determined the other subject is the Flow.

It might be remarked here that the investigation has been on the way through several important stages upon the assumption that there is an output and that it will be within some general limits and that no such fact is warranted until the available flow is known; but it has also been taken for granted by the author that such an investigation has been delegated to an experienced hydraulic practitioner. A physician or an attorney does not need to go into details to advise in a general way as to his client's illness or claim, and the hydro-electric specialist can estimate the probable power output, knowing the fall, quite as promptly; he need not leave his office to do so, but should be able to quote the high, low and normal run-off of any power stream in this country after a few minutes' reference to existing records and he should be equally prepared to estimate the catchment area which is tributary to the power site and therefore the available power flow in a like brief period.

The "flow" is that portion of precipitation which does not evaporate; the latter term includes all the water taken up by vegetation and which vaporizes from the land and water surfaces. This flow comes into the stream as surface and ground run-off and fluctuates in volume in accordance with that of precipitation and the ground storage capacity of the catchment area. The extremes may be illustrated by the area of the Cumberland river where it emerges from the foot hills at Cumberland Falls and that of the Manistee river in Michigan, the former is a very hilly and rocky country, the latter is level with deep drift; from the Cumberland water shed, precipitation runs off entirely on the surface and the flood flow of the stream is one hundred times that of the low flow; on the Manistee water shed, the precipitation sinks chiefly into the soil and thence feeds into the stream gradually and the flood flow is not quite double that of the low flow, nor are these illustrations of greatest extremes. The drainage area run-off of the large majority of rivers and their important tributaries has been well established from flow measurements carried on by the Federal Government and by several States in co-operation with the former and the facts may be found in public records, and so thoroughly are all sections of this country now covered by this informa-

tion that the run-off from water sheds where no measurements have been made can readily be determined from comparisons of water shed conditions and precipitation volume with some of which the run-off is known. In this manner the monthly flow for one of recent years, preferably a dry year of low precipitation, may be readily found and from it the volume which is to be taken as the lowest permissible basis for the power development must be selected and this becomes the available power flow for the project. Plotting the monthly mean flow for such a year in profile, depicts the fluctuations graphically, reveals the lowest volume and its locus and the next and so on. Generally this low flow is found in the late summer and frequently in sequence for two or three months because this is the season of greatest vegetable growth and consequential water absorption, and also most generally the season of low precipitation, all of which conditions combine to deplete the ground storage volume and reduce the flow until replenished in the fall months by plenteous rains and reduced vegetation requirements for moisture. In northern latitudes the low flow months are found just before the spring break up because most or all of the winter precipitation is frozen. To correctly select the available power flow from these low months is the result only of a clear appreciation of the market value of the product; where this is abnormally high and the available power current revenue not only meets the charges but leaves a surplus, then the available flow may be taken considerably above the low flow volume because the market permits the expenditure of investment in and operation of an auxiliary power plant or of water or current storage; it is precisely this measure of the commercial ability of the market to sustain such an auxiliary program to a certain extent of output and period which must fix the available power flow at some point above the lowest monthly. This reasoning will generally warrant to accept the flow which is available during nine months of a normal precipitation year, leaving three to four months (the latter during dry years) when the natural flow must be added to from water storage or pondage, or the hydro power output must be increased by that from an auxiliary power or electric storage plant.

Many developments of the past have been planed upon too high a flow basis and the otherwise safe market does not support the excessive auxiliary installation and thus they forfeit the advantage of the hydro source by paying too heavy a tribute to the auxiliary plant.

There is no problem or difficulty in definitely selecting the proper flow limit provided a market analysis as outlined at the outset is available, nor need there be any uncertainty as to the run-off from the catchment basin, and from these two the flow basis can be determined with entire reliability. This furnishes the data for the finding of the power output, the salable current output, which with obtainable turbine, generator and transmission efficiencies is seventy per cent of the hydro source; or 12.5 cu. ft. second of water are

good for one delivered electric H. P. for each foot of fall. We are now approaching the second line of inquiries, those which will culminate in revealing the cost of this power output. It may again be in order to note that this inquiry has proceeded at considerable expense already to the investigators and so far they have been and are in the dark as to the cost of this power output, which might possibly be prohibitive as to the entire enterprise. Again it must be repeated that it is assumed the investigating business is in the hands of a specialist who does not need to make detail surveys and prepare plans to arrive at some, of course only approximate, estimate. The experienced hydro-electric practitioner can go to the site of the proposed development and with a Stadia-level, an instrument with which vertical and horizontal measurements are made optically across a wide river, from bank to bank, without having to use a chain or a transit, and with the use of a boat and the assistance of one man, he can secure all necessary data for the profile of the river and the valley which has to be closed by the dam structure, and this should not take more than a few hours, and from such a profile he can compile an estimate of the cost of the required works and of the generating power equipment in another hour or so and the result should be within ten per cent of the final estimate, which will be the result of all the detail surveys, the plans and specifications; the discrepancy in this preliminary from the final should be on the side of safety, that is in excess of the final.

However the cost of output now under discussion, is that found from an accurate estimate taken from detail plans which are based upon precise surveys; no other should be accepted for the final analysis of the project. First then, the development program must be formed; if all the fall is accumulated and utilized at the same point it is a direct development; if however the whole or part of the fall is obtained and used at some distance down stream from its origin, then the development is of the diversion class and may be short or distant. The works of the direct program consist of a dam and a power station at or near by; the diversion program may or may not require a complete or partial dam but includes a conduit of open or closed type and a power station at its terminal. Comparative cost is the chief criterion as to program; in the author's judgment not sufficient study is given to the diversion programs though the old mill power developments were almost entirely of this type.

The dam consists of the spillway and reservoir sections, the former occupying the river channel, the latter closing the remainder of the valley. The site to be occupied by these must be surveyed to one foot contours and the sub-surface formations must be developed by borings down to ledge rock or into impermeable material, that is clay *in situ*. The type of spillway is chosen with proper regard for the required height, overflow, character of surface and sub-surface material and proximity of construction material. The length is

fixed by the width of the normal river channel, its height by the fall to be utilized. In soft alluvial formations, the gravity spillway is preferable but in rock sites the solid type; within the height of 20 ft., timber spillways are applicable, provided the material is considerably less costly than that for concrete; up to 100 ft. height concrete is a safe spillway material; for those exceeding this limit granite should be used. The overflow of spillways should not exceed 0.2 of their height, the section of solid spillways is of a vertical upstream face, a rounded crest or crown and a curved or ogee shaped downstream side; its base is 0.8 and the crown 0.12 of its height, and of such general dimensions that the solid concrete section represents a safety factor against sliding (with proper foundation connections) of 2 and against overturning of 3; the section volume is half of the square of 1.2 of the height. The gravity section has an upstream face with a slope of 1 to 1, a rounded crown and a downstream side with a slope of 1 to ½; its base is 1.7, and the crown 0.2 of its height; up and down stream faces are of steel, timber or concrete-steel blankets connected to interior transverse partition walls of similar constructions, placed from 10 to 16 ft. centers. The foundations of all spillways are of a concrete sheet 2 ft. thick, overhanging the spillway section for 0.3 of its height on the upstream and for a distance equal to the spillway's height on the downstream side. The upstream foundation end, connects to a "cut-off" being a concrete wall sunk into rock or into soft material to a depth reaching impermeable clay; when this is deeper than half the spillway height, the cut-off stands on a sheet pile curtain, of timber or steel, as the material may be suitable for the driving through it. The foundation blanket is broken, up and downstreamward, into longitudinal arches of a width equal to 0.3 the spillway height, with slight rise, terminating in 3 ft. deep and wide longitudinal concrete strain walls; in very soft beds, these strain walls rest on timber strain piles set 8 ft. centers and driven with some downstream batter.

The reservoir dam structures, are of earth fill with concrete core-wall, the latter being connected to and in continuation of the spillway cut-off; if suitable material for such an embankment, which should be a puddled mixture of sand, loam and clay, is not available within an economical haul, concrete-steel bulkheads may be substituted of the upstream half-section of the heretofore described gravity spillway with a cut-off along the heel connecting to the spillway cut-off. Reservoir structures should rise 5 ft. above the fixed spillway overflow level.

The spillway should have a waste or sluice capacity, sufficient to pass the flood flow of the stream which is not to flow through the turbines and power station; the gates should preferably be of the simplest construction, such as stop logs with power operating devices; one of these should reach the lower pool elevation so that the upper may be unwatered in low flow season for purpose of inspection and repair of the upstream spillway and power station parts.

The power station may be at the end of the spillway, or just downstream of it, or it may be in the interior of the spillway itself, when its height is 20 ft. from normal lower pool level. The power station design, may be of the drowned or dry penstock class; the first when the upper water stands in the turbine chambers, the second when the water is taken to the turbines through pipes. The drowned type is available for heads up to 25 ft. and is somewhat less costly than the other. The plan of the power station for penstock or turbine chamber units, is from 12 to 18 ft. wide and 20 to 40 ft. long, according to the character of the turbine units; the foundation is that of the spillway extended; its sub-structure consists of one upstream and two end walls, with such a number of partition walls as is required by the number of power units; the lower level water enters into this sub-structure and that from the turbines is discharged into it; the downstream side remains open; the turbine floor, rests upon the sub-structure; the end walls and the partitions are continued upward; the upstream side remains open, if of the drowned penstock type, and the downstream end is closed by a masonry or steel bulkhead. The electric generators may be placed on the turbine floor or down stream from the penstock bulkhead when the turbine installation is on horizontal shafts, or it may be placed above the penstocks when turbines are on vertical shafts. Drowned penstocks have to be provided with gates and trash-racks.

The generating equipment consists of the hydraulic and electric machinery; the units are planed to best meet the market requirements; large units are preferable, the obtainable speed and efficiency of output together with cost of apparatus are the criterion. Regulation equipment consists of hydraulic governors and electric devices.

Transmission equipment is made up of the line and transformers. Hydro-electric current is generally transmitted a considerable distance in order to find a suitable market. The limitation of distance lies only in the cost of the equipment and the value of the energy lost during transmission. The transmission loss is controlled by the current quantity, the pressure and the distance; there is no limit to practical pressure or voltage and therefore with sufficient current there is no limit to distance, at least not within the practical scope of this discussion. A safe, though arbitrary rule, is that the current should aggregate 15 kw. per 1000 ft. of transmission distance or about 80 kw. per mile; that the pressure should not be less than 5000 volts for any distance, with 500 volts additional, for every mile exceeding five. The observance of these, will keep the economical loss within 7% for transmission distances up to 25 miles and within 9% up to 100 miles, while the transmission cost will approximate $25.00 per kw., being a charge of about 0.2 cent per kw. hr. on a 3000 hour, annual operation period; this represents charges of investment, maintenance, depreciation and operation, with the price of copper taken at 15 cents per pound.

The analysis of the project is now closed and when shaped into a proper report, will reveal the available market and the probable revenue from current sales, the feasibility of controlling the development, the output and its cost as based upon a definite development program.

It seems clear that such an investigation consists of three distinct functions which may and should be treated as separate operations and topics, namely the market, the approximation of output and cost, and the precise estimate of these; when thus approached there need be no costly disappointments. The initial treatment of the market and approximate output and cost topics need not be costly nor do they require much time, while the expense of the precise determination of the two latter, may reach 2½% of the cost of small undertakings of this character and somewhat less for larger ones, and will require sufficient time to make the detail surveys and prepare the plans and specifications.

Discussion

President Loweth: This Society is to be congratulated on having so interesting a paper presented to us this evening by Mr. von Schon. It is now before you for discussion.

Mr. L. K. Sherman, M.W.S.E. (by letter): Mr. von Schon has presented in a concise and systematic manner the preliminary features in investigating a proposed water power development. The most important part of such an investigation is the determination of the stream flow. Storage basins are often prohibitory from a financial and economic standpoint. The amount of minimum monthly stream flow will usually determine whether a water power is economical in comparison with steam.

Recently the writer reported upon the power of a stream in Iowa. Government reports on the flow of a stream in a neighborhood drainage basin were available. Also, very complete and extensive records of rainfall were at hand. A careful comparison was made between the variations of flow and the periods of rainfall. This comparison failed to show any relation between rainfall and run off, either in amount or in time. The writer considers any estimate of stream flow for water power, based on rainfall, as worthless and misleading. In case stream flow records are not available for the basin in question, the flow can be closely estimated by judicious comparison with a measured stream whose basin is similar in condition of topography and precipitation.

In this connection the writer would call attention to the need, in streams located in the middle west, of a type of power plant available for very low heads but which need not, of necessity, be economical in the amount of water used. A satisfactory plant of this type would utilize many powers which on account of reduced head in time of flood are now going to waste.

Mr. H. von Schon: Mr. Sherman calls attention to the comparison "between the variations of stream flow and the periods of rainfall," in connection with a stream in Iowa, and states that "the comparison failed to show any relation between rainfall and run-off, either in amount or in time." I do not doubt his experience, but can cite another experience in connection with the investigations some years ago on the Kentucky river near Frankfort, where leases had been secured for water power at navigation dams. Some of those dams were built by the state of Kentucky before the war, and passed into the possession of the Federal Government. On all Government dams, gauges are read daily. The record at Frankfort, Kentucky, covers about fifty years, which furnishes a most desirable foundation for flow investigations. I recognized the opportunity for comparison with rainfall deductions and found that the two discharge curves were almost identical except for a small discrepancy in the winter months. Rainfall data of a fifteen year period were used, as the cycle of precipitation comprises about seven years, that is seven years are likely to include a low precipitation, or a dry year.

In regard to Mr. Sherman's remark about a type of power plant available for very low heads, it may be stated that one of the largest developments now completing in Germany, is of a 2-½ ft. head; there they have gotten down to the scrapings. Of course that is not an economical power.

Mr. L. E. Cooley, M.W.S.E. There is one feature in connection with this paper that I might or might not, be disposed to criticise, if I had the time to study the text carefully. I think the paper is a valuable one, as giving a complete exhibit to the young engineer of a method of procedure for developing and analysing a water-power project.

It occurs to me that the paper is chiefly instructive (probably that is the purpose of it), in exhibiting the details and economies of existing practice in steam plants, in comparison with central station work for a hydro-electric plant, and the material brought together in that connection, is certainly valuable and instructive, and required great labor to compile.

Everyone will agree, that for small plants and many installations of great variety and uses, the electric motor is better adapted than shaft distribution by steam, and the paper in this respect makes useful comparisons which are valuable to a person who wishes to substitute electric current for steam power. But it seems to me that the comparison to be made, is between the use of electric current and the direct use of steam or internal combustion engines; also, that the comparison would be more legitimate if applied to a central station steam plant. In other words, the comparison should be made between a central station steam plant and a water power plant. That is the problem involved, as I understand it, in the Commonwealth Edison station in this city, which distributes power

in the same way as would be done from a hydro-electric plant. They have brought down the cost of steam in the turbine engine to something less than 0.5 cents per H. P. hr. A project in Missouri, was rejected by the Westinghouse company because it was not safe to undertake a water-power proposition in view of the fact that central station plants were in sight to supply power at less than 0.5 cents per H. P. hr.

In making some comparisons in 1901, I gave considerable study to the subject in connection with a water-power project at Keokuk, Iowa, for 60,000 horse power, by means of a dam at the foot of the Des Moines Rapids. At that time it seemed to me that the practice in high class steam plants, justified an estimate of 0.6 cents per H. P. hr., for constant steam-power; 0.8 cents per H. P. hr for factory or daylight power (ten or twelve hours per day); and 1 cent per H. P. hr. for variable power such as is used in lighting and in trolley work.

I have had occasion to design dams for bad sites on alluvial streams. Experience with the Barrage at the head of the Nile delta shows that it is possible to build a dam on any site. The original dam failed, but was finally repaired by sealing the river bed with clay some one-hundred yards up stream. Since then the dam has been a success. In such locations I have followed the French practice of the tumble-bay dam, where all the forces of the overfall are confined within the structure. If I am not mistaken, attention was not called to this type of structure for difficult location. I do not mention this by way of criticism, but simply an addition to the methods of treatment offered by the author.

I will not follow the subject further than to discuss the thoughts presented in the opening paragraphs, in regard to the conservation of our water resources. It is the one resource next in value to the land. There is water power in this country capable of development in excess of all the power now used—both water and steam. The water-power that may be developed by conservation, will exceed all the power that can be produced by high grade steam engines with all the coal mined in the United States, or about 450,000,000 tons last year. You can see the tremendous significance of a proposition of this character and how far it reaches. It may not only save our coal resources but will produce reservoirs for fisheries and recreation; mitigate floods and equalize the flow of streams, thus making valleys salubrious and aiding navigation. Water conservation reaches further than any other measure. In this discussion of a water-power proposition, I do not like to see the subject discussed from a purely commercial standpoint without regard to public welfare. Our streams are too valuable, their relations are too manifold, and their uses are too varied to permit mere local exploitation. The power itself (water-power especially), is so nearly akin to a fundamental resource, like rainfall, sunlight and air, that we should not go ahead blindly and allow it to become

the subject of monopoly and trust. There are many cases on record where the public has been greatly embarrassed in not being forehanded in such matters, and some of them are in the state of Illinois, but I think we shall be able to clear the right of way for the deep waterway and make the great water powers produced thereby, the subject of state ownership. There are other cases of abuses which have grown up, almost incapable of remedying. We are liable to have our resources squandered by reason of lack of system. Developments are made in such a manner that only part of the power of a stream is utilized. I mention this, not by way of disagreement, but I do wish to see water power developed to the full possibilities. The point I wish to make in this connection is, that it is up to our Legislators, and up to the engineers as advisors, to formulate a public policy for the systematic use of our waters, which will preserve every right and which will result in a systematized development of water-power and eventually a great increase of that water power by means of storage. Just what form this should take I am not now prepared to say, but I think we are liable to invite complications and blighting controls of fundamental resources, greater than those heretofore complained of by the people.

Mr. von Schon: I wish to thank Mr. Cooley for his courtesy in handling my paper as kindly as he has.

With reference to the power cost of large central plants, I will say that at 0.6 cents per H. P. hr. of continuous service, the annual cost is $52.00 per H. P. 20,000 H. P. run at the "Soo," on a 25-year contract for $10.00 per H. P. per year, continuous power; at Masena, N. Y., contracts have been made at $8.00; at Niagara, at $19.50; this, on continuous service, would be less than 0.25 cents. When hydro-electric power is developed at $150.00 per H. P. delivered, it can be served at a lower resourceful rate, than by a steam plant burning free fuel; that is, unit for unit.

In regard to the conservation of our water resources, you will not find a greater champion than I am. I have just contributed an article to the "Engineering Magazine" on "Use and Conservation of Water-Power Resources," which will be followed by other articles.

Mr. Cooley: I did not mean to convey the idea that I doubted that water power could be produced cheaper than steam. I have made estimates showing that water power could be produced at a profit of $10.00 per year, as mentioned. What I designed to do was simply to call attention to the fact that comparisons should be made between central working steam plants and water power plants, rather than with the character of local steam plants found in shops and factories.

Mr. W. L. Abbott, M.W.S.E.: It would be somewhat presumptuous on my part to criticise this paper, in the presence of such eminent hydro-electricians as have already spoken, but having

been raised on steam, I venture, in spite of the doleful prediction for that prime mover, to speak a little in its defense.

The author in his opening sentences, speaks of the wasteful void which will be left in the ground when a deposit of coal, oil or gas is removed—a void which will never be filled again. That is a problem which may worry future generations, but the power user of the present day, who is able to buy coal in the ground in almost unlimited quantities at a price less than one cent per ton, will locate his mill in densely populated, coal underlaid, fruitful lands, rather than by a dam site in a wilderness where nobody wants the power, or attempt to transmit this power long distances at a cost which the author estimates at $25.00 per kilowatt and have his service dependent upon the maintenance of this long transmission line.

I do not believe in discouraging water powers: on the contrary I believe they should be encouraged, as auxiliaries to steam plants. The rate of flow of water is up and down; the demand for power is up and down. The flow of water varies with the season, regardless of the demand for power, which later varies with the hours of the day. The average demand for power during the year is about one-third of the maximum demand, and the inelasticity of hydraulic power renders it unable to meet this demand without sacrificing two-thirds of the power available at minimum flow and all the excess at maximum flow. If the hydraulic power were available within reasonable proximity of a large market, the demand should be filled, in the main, by power generated in a steam plant, with an auxiliary source from the power from this hydraulic development, which may be so loaded as to use its full output day and night, season in and season out, the year round. This would amount to possibly one-third of the maximum demand of the power market; the balance of it is to be taken care of by the steam plant, which would generate the greater part of the power. In this way the full flow of the water power would be utilized the year round (except for flood waters which would necessarily be wasted) thus saving some fuel expense, and the steam plant would always be available as a guarantee of the continuity of the service.

The author enters quite fully into the discussion of the first cost and the operating cost of steam and other plants of small capacity. I regret that he did not include in this—as also suggested by Mr. Cooley—a comparison between the first cost and the operating cost of modern steam plants of large capacities, and the cost of hydraulic power plants of the same capacities, including the land and the transmission lines. I am convinced that such a comparison would show to the disadvantage of the average hydro-electric plant. The steam turbine, in the large sizes to which it is now developed, has reduced both the initial cost and the operating cost to such a point, that in localities where coal can be secured at a moderate price, water power must be readily available and must be inexpensive

of development, if it is to compete with steam power in average commercial business having the usual power factor of 30 %.

Mr. von Schon: In regard to Mr. Abbott's views of the relation between steam and hydraulic plants, I do not claim that a hydraulic development is complete without an auxiliary. One of my best friends has said that in looking for a water power, one should look for a chimney on the river, and I fully endorse this. I have never made an estimate on a hydraulic plant without an estimate on a chimney. However, I cannot agree with the statement that the hydraulic plant is to be auxiliary to the steam.

The cost of a modern steam plant of large capacity was not included in this paper for the reason that the subject was fully covered in four articles which appeared in the April, June, July and August issues of the "Engineering Magazine" of last year.

We think we have a very high efficiency steam plant in Detroit, of 8,000 H. P. units, but some 200 miles from that city is a water power of not quite 22,000 H. P., and estimates at the present price of power and cement may show that hydro electric power can be furnished at Detroit at 0.5 cents per kw. hour, and make a paying investment of the hydro-electric development. The operating cost of a large power plant is the kernel of the nut; how many tons of coal would the 50,000 H. P. plant at the "Soo" burn? how many car loads every day? Consider the time and labor used in handling the coal, firing the boilers, handling the ashes etc. and the cost of operation of the plant, maintaining, repairing, superintending, etc. Of the 50,000 H. P. available at the "Soo," 27,000 H. P. is in use, and the cost of actual operation of that plant is less than $5000 a year.

President Loweth: The author says that for every city in these United States not now enjoying economical power, that there is water-power available for economical use for such city. The speaker has in mind several cities where it would appear to be commercially impracticable, if at all practicable, to develop water-power to the extent of but a small portion of that required by these cities. For instance: New Orleans, Cleveland, Omaha and Kansas City. Doubtless there are water powers in the vicinities of these cities capable of economical development, but doubtless they could more profitably be utilized by the smaller cities nearer by, and the aggregate, available for the larger cities named would be much less than would meet the requirements. Many other cities no more favorably located might be named.

Mr. von Schon: I could go to my files and point out an available water power for every considerable town in need of economical current.

The Wisconsin Valley Improvement Co. has been given authority to build dams and collect a tax from every owner of the 175,000 H. P. which are today available on the Wisconsin river, (exclusive of the tributaries) of which less than 20,000 H. P. is developed.

If the Wisconsin Valley Improvement Co. carries out its contract with the state, under which they are obliged to store two billion cubic feet of water before they can charge toll, they will increase the development to 300,000 H. P. I am talking of the conserved energy—that is, of the economical development of the full water-power. Milwaukee, I believe, can get power from the Wisconsin river, or from the Menominee river, which has a large and steady flow. That river cannot be more than 150 to 200 miles from Milwaukee. In Germany, power has been transmitted 328 miles, since 1901. It is simply a question of voltage. Why not go 500 miles for power? I think there is no one here, who has had electrical experience, who doubts the perfect practicability of 200,000 volts on transmission lines, and that we shall come to that practice within a few years, since the difficulty with the insulators has been overcome. It is not now necessary to have three or four petticoats on the insulator, for it is being suspended. In Florida there is a large project on foot to develop water power from the Suwannee river, where there is a capacity for 32 feet. I know of an opportunity furnishing 50,000 H. P. to Cincinnati and purify that smoke-ridden city, making it as clean at Detroit.

Mr. J. H. Warder, M.W.S.E.: What is the source of water-power for Cincinnati?

Mr. von Schon: It is the Niagara of the south—the Cumberland Falls—about 150 miles away. At its site, or near it, there is not a demand for the power. If the Government will grant franchises to build reservoirs on the Kentucky river, 80,000 H. P. can be developed on that river, and some of that 80,000 H. P. can be taken to Louisville and some to Cincinnati. An English syndicate sent over an engineer, last year, who reported that 20,000 H. P. could be developed economically at the Louisville Falls of the Ohio river.

It is simply a question of conserving what there is; of stopping waste; of taking account of what the country has and using it properly.

There is one large water-power source additional to that discussed, which will be used eventually: that is the ever-moving waves of the ocean. This power is being harnessed now, to do the work of men, but not as economically as it might be. Give me a machine which combines hydraulic turbine and electric generator, and I will furnish all the power that can ever be utilized from the action of the waves.

Mr. A. Bement, M.W.S.E. (by letter): This paper is a particularly valuable one, because it deals with a branch of engineering which is of rapidly increasing importance, and regarding which there has been too little data available, and I am sure Mr. von Schon can give us some further information on the subject. I would ask what proportion of the water power plants operated by private corporations are paying dividends, or how many plants owned by munici-

palities or otherwise, are earning a proper return on investment, and also what proportion are not doing so.

Daniel W. Mead, M.W.S.E. (by letter): To the mind of the writer, the author of this paper, inadvertantly perhaps, gives a false idea of the facility with which the expert or experienced engineer can intelligently pass, even in "a general way," on the possible power output of any stream. The physician, attorney or engineer who stands ready on a few moments' investigation to give even general advice to his client, is liable to give advice that is seriously misleading, and the same may be said of conclusons drawn from any survey made in a few hours' time.

It is true that an office estimate will frequently give a general idea of the feasibility of a project and the possibility of a development, and that hasty field examination will sometimes give the basis of an approximate estimate of cost on which the engineer or owner may decide whether or not the project is worthy of further consideration. Conclusions drawn from such hasty examination should be made on a conservative basis, and made subject to the modifications which must usually result from a detailed examination. Estimates cannot be relied on within the limits set by the author of the paper. It is indeed doubtful if, after the most careful examination and after the completion of detailed plans and specifications, that any engnieer can make an estimate in the face of the contingencies of construction, the changing values of our markets, and the varying effects on cost of a scarcity or superabundance of labor that will not vary more than ten per cent. from the actual cost, especially if considerable time elapses between the time when the estimate is made and the time when the contract is consummated.

The study of stream flow is worthy of much more attention than the paper would indicate, and of more than it generally receives. Maximum, minimum and mean flows are only of incidental interest. A knowledge of the varying power conditions should be based on a study of the daily hydrograph not only for one year but for all the years for which the data can be obtained. Even the best information now available is unsatisfactory, and the engineer who is developing a power project must call to his aid all possible sources of information on which to base his conclusions. Not only the stream flow but the storage possibilities, which can be determined only by careful surveys, must receive the most careful consideration, for adequate storage frequently means the success or failure of the project. With small flows and high heads, storage may maintain an average flow many times the minimum. In several projects now under way, where heads of from 75 to 100 feet are being developed, the practicable storage found, has increased four to six times or more the average flow obtainable over the minimum flow available without storage.

The general rules of design, which are briefly stated in the paper, are understood to be the author's conclusions as to the best

practice and show his familiarity with the subject he is discussing. They are not safe guides for design and construction to either owners of water power or experienced engineers. Every location is a problem in itself which for the best results must receive entirely distinct and separate study; and almost any simple rule, such as those outlined by the author, may under many circumstances, be found entirely at fault. Such rules are for this reason of somewhat questionable value, unless fully discussed, for they are not needed by the engineer familiar with the subject and they are apt to be misleading to those without experience.

In the paper under discussion there is a pervading spirit of unwarranted optimism in regard to hydro-electric developments which is apt to be misleading and which might result, if unquestioned, in the encouragement of the popular fallacies as to the golden opportunities offered by any and every water power possibility which is yet undeveloped. There is a popular notion that the ownership of a water power privilege is equivalent to a fortune for its lucky possessor. While a detailed examination of the paper under discussion by any one familiar with these projects would indicate that the writer recognizes the difficulties in the way of successful development, yet there are many of the factors on which the success of a hydro-electric project depends to which attention should be especially drawn and the importance of which should be emphasized.

Taken in the abstract, the probable value of water powers to humanity, especially in the future, is very great and they should receive the most careful consideration and study. At the present time, and to present investors, the value of these powers for immediate development is, however, more than doubtful. The successful commercial development of a water power project is a very complex problem involving not only the elements of adequate head and flow of a stream, but many other elements which the writer of the paper has discussed in some detail. It should be strongly emphasized that all of these elements must be capable of suitable adjustment before any such project can be commercially successful. Many water power projects that have been already developed have resulted in unfortunate losses for those who have invested their money in them; and while, in a number of instances, the profits have proved highly remunerative, or at least given great promise of satisfactory returns, there are comparatively few where the returns are larger than are fully warranted when the risk of the project is considered.

One of the earliest and largest hydro-electric plants developed in this country, a plant which has been regarded by many as a monument to the engineering skill of two continents and which has now been in operation for twenty years, within a short distance of an extensive market, has, I understand, not yet paid a dividend. Two other large and well known developments, widely

heralded and fully described in the engineering press, have, after some ten years of existence, gone into the hands of a receiver and been sold at much below their original cost. It still remains to be demonstrated whether these powers can be made to pay on their greatly reduced capitalization.

The business man and investor of today is only casually interested in humanity a thousand years hence. What may happen when the coal supply and the supply of natural gas, or other limited sources of potential energy are exhausted affords an interesting subject of inquiry to the student, but the investor and his active lieutenant, the engineer, are interested in the inquiry, "Can the investment be made to pay in the near future?" "Can returns be confidently expected, perhaps not immediately after construction, but within a time not so remote but that the interest on the capital invested for both construction and development is assured?" If this cannot be reasonably demonstrated, the investment is unwarranted and affords only an opportunity for the promoter to reap an unfair profit from credulous investors.

Water power should be regarded in the same light, as with any other business investment, and it should be undertaken only when it is clearly apparent.

First: That there is an adequate available market.

Second: That a fair price can be obtained for power.

Third: That the plant can be developed at reasonable expense.

Fourth: That the fixed charges and operating expenses can be met by the income from the plant, with a margin for profit.

Fifth:—That an adequate head and flow are at all times available; or

Sixth: That the income will warrant the installation and operation of auxiliary power, at times of inadequate hydraulic power, or that the market will admit of the temporary interruptions due to loss of head or reduced flow.

The course of all new developments is the speculative spirit. There are always many who see in something new, or partially unknown, the chance to realize large returns from small investments. Promoters, taking advantage of this human weakness, frequently mislead the unsuspecting public by calling attention to the great natural resources that are unutilized and hence going to waste, conveying the idea that these are only to be conserved in order to afford rich returns. There is just truth enough in such ideas to make them misleading, for, while in some cases the returns from such conservation may be large, in many more cases the returns will be, under the present conditions, entirely inadequate to meet the expense involved, and hopes built on such conditions are entirely unfounded and born only to be blasted. The prevailing idea that economical energy from water powers can at present be made available for every community is erroneous. Under present conditions it is impracticable to serve many communities with power

generated by water and transmitted by electricity, and any attempt to do so will result in financial failure.

The estimates of power costs of the Hydro-Electric Power Commission of Ontario, referred to by the writer, are of great interest and value. It should be particularly noted, however, that they are wholly inapplicable to many localities without material modification, and, if used without such modification as a basis of estimate, will often give widely erroneous results. These estimates are based on coal at $3.50 per ton, while in many cases the actual cost of fuel is only one-third to one-half of that price. They include fixed charges which must often be eliminated from consideration by the competing water power. They contain no consideration of the exhaust value of the steam, which is often an important item. They contain estimates of labor which in many small plants, especially where gas engines are used, is largely eliminated by the party in charge being engaged for a large portion of his time in other work and but little expense to operation, being fairly chargeable to the plant.

At the present time the competition between hydro-electric and steam energy is not one of power only. In many cases the exhaust steam has so high a value, or is so essential to the manufacturing processes, that the power is almost or quite a by-product. In other cases, during the portion of the year when the factories or mills must be heated, the exhaust has a high value for this purpose which is of great importance in the consideration of steam versus water power.

The existence of the present steam installation frequently makes it necessary for the hydro-electric plant to compete against the steam plant—not on the grounds of fixed charges plus coal and operating expenses, but on operating expenses plus only a portion of the coal costs, for the expenditures on which fixed charges are based have already been entailed and cannot be considered in the actual competition of the two sources of power.

When the fixed charges in the hydro-electric plant are high, and the cost of maintenance, depreciation and operation are large, the competition of the steam plant cannot be set aside by optimistic statements but must be considered on substantial ground.

The rearrangement of factories and mills to accommodate new methods, is a matter of time, and time is indeed money where a heavy investment is awaiting a market for returns.

Many water power developments with their long electric transmissions are not designed and constructed on a basis sufficiently dependable, and are not sufficiently free from possible interruption, to make them always desirable for all purposes.

All of these items must receive due consideration, and the estimates of the actual cost of power, against which the hydro-electric plant must compete must be based on local considerations, not only of the community in which the power is to be utilized, but of the

various plants in which an endeavor is made to replace the power now in use.

Most of the points raised in this discussion may be inferred from the paper discussed, but many of them may remain unnoticed unless the paper is carefully analyzed.

The apparent scheme of analysis outlined in the paper seems fundamentally wrong. If we grant that every community has a hydro-electric development at its command, then the investigation of the power market may be the first consideration; but in most cases it becomes the question of a power project seeking a market, and the first question of importance is the quantity of power, its reliability, and the possibility of its economical development. If these questions are answered fairly favorably, then the careful scrutiny of the market becomes essential. Each factor is of quite equal importance, and, if each seems fairly favorable and if the feasibility of the entire project is to receive due consideration, the investigation of each must go hand in hand.

We are living in an enthusiastic age as regards hydraulic developments, and the conservation of natural resources is on every tongue. It seems to be the fashion to look into the future and see almost every stream navigable; to see the commerce of the world sailing into Chicago markets; to see the arid lands of the West "blossom as the rose," and our factories and homes fully supplied with power and heat by our abundant water powers. These are but Utopian dreams in which the engineer should have no share. There are sufficient opportunities for broad developments in all lines. Irrigation, drainage, water powers, internal navigation, are all subjects of vast importance and should command the careful and sane consideration of our citizens, our statesmen and our engineers; but unless they are so discussed and considered, and unless their developments are based on an intelligent commercial basis, we shall surely face failures and inexcusable waste. All such developments must stand the test of careful, thoughtful and thorough investigation and should be attempted only when their value to either the community or the individual is fully understood and demonstrated.

CLOSURE.

Mr. von Schon: My claim as to the value and reliability of the preliminary report and office estimate of power output, feasibility, etc., cannot be misunderstood as applying to anyone excepting the expert, and in this sense, conveys no false idea as to his facilities to form such conclusions as are expected for preliminary guidance, which is all that is set up in my paper in this connection. The final estimates should, as emphasized in the paper, be based only upon detail surveys, borings, etc. The unit values of materials and labor on which this estimate is based are therein quoted and their fluctuations therefore have no effect upon its reliability, as they can be readily compensated for. Such estimates can meet the ac-

tual cost within 10% if the estimator is a practical constructor as well as an experienced designer. Estimates based upon theoretical construction program and methods, are certainly not admitted by me to the class referred in the paper.

Of the same character is the comment upon the statements in this paper regarding the availability of standard designs; they are certainly not claimed to be safe guides for the inexperienced engineer, but they are for the experienced constructor and to none else should such plants be entrusted. Certainly every location has its characteristics and there are standards of designs for each.

The estimates of Steam Power cost, compiled by the hydro-electric Commission of Ontario cannot mislead him who reads; the fuel cost basis is plainly given, and also a correction table for other coal costs; labor on small unit plants is not charged up for a full day but proportionally; the value of exhaust steam is an exception rather than a rule, but when all the conditions are unfavorable for the hydro-electric and extremely favorable for the steam plant, then very likely the balance will be in favor of the latter. However, the paper emphasizes all these points as being entitled to specific individual analysis and the steam power cost of the tables is not claimed to hold in any case.

It is stated that the apparent scheme of the analysis outlined in the paper, seems fundamentally wrong, in that the market investigation is not the logically first important topic. The author maintains that this should be the first of the engineers' analytical topics, because the existence of a water power of some sort is known to the promoter when he engages the engineer, and very often the promoter knows a good deal about it, but he falls into a common error, expressed in the discussion that the market matter can wait and he would have the engineer go out in the woods with a crew of men and spend several days making surveys, when an intelligent canvass of the markets' capacity in one day, may veto the commercial feasibility of the best possible water-power opportunity.

METHODS OF STUDYING THE HEAT-ABSORBING PROPERTIES OF STEAM BOILERS

LOYD R. STOWE.

Presented October 7, 1908.

INTRODUCTORY.

There is no subject in the broad scope of mechanical engineering that has progressed as slowly as that of boiler design, where thermal efficiency is to be considered. The problem of arranging heating surface so that it will absorb the highest per cent. of heat presented to it is one that is little understood. By comparison, the amount of literature on the way in which hot gases give up their heat, through cooling surfaces, becomes very small when the large amount of information on most other engineering subjects is considered. The boiler purchaser can easily enough make his choice when strength, maintenance and the like are considered, but when he has to consider fuel economy it is doubtful if he can, with authority, say which boiler is the most efficient. In general, this property is the one that is least seriously considered. It seems strange that this subject of the transfer of heat from gases to water has not been attacked in a more serious manner, when we consider that since the introduction of steam for power, the boiler has played the most important part in the field of mechanical engineering.

The object of this paper is to show that if all possible care is taken to secure accurate and complete data, when tests of steam generators are made, we can by going beyond the usual calculations arrive at data which may at least introduce us into this field of investigation. In order that the meaning of terms used in this paper will be properly interpreted, data and calculations of an assumed test are here given.

DATA AND CALCULATIONS.

Grate Efficiency.—E_g.

Wet coal used per hour............................1121 lbs.
Refuse from furnace per hour..........................179 lbs.
Pounds of refuse from one pound of wet coal (179÷1121)..................................0.1597 lbs.

Analysis of wet coal, refuse and fuel arising from the grate:

	A	B	C	D
	Composition of one pound of wet coal	Composition of one pound of refuse	Composition of refuse from one pound of wet coal (Column B times 0.1597)	Fuel from one pound of wet coal that arises from the grate (Columns A-C)
Moisture	0.0969	0.0000	0.0000	0.0969
Carbon	0.5790	0.1240	0.0198	0.5592
Hydrogen	0.0409	0.0098	0.0016	0.0393
Oxygen	0.0774	0.0263	0.0042	0.0732
Nitrogen	0.0100	0.0042	0.0007	0.0093
Sulphur	0.0438	0.0179	0.0028	0.0410
Ash	0.1520	0.8178	0.1306	0.0214
Total	1.0000	1.0000	0.1597	0.8403
Calorific value of wet coal and refuse in B. t. u.	10706	2324	371	10335

Column D represents the fuel that ascended from the grate for every pound of wet coal used and the heat that the grate has made possible to be developed in the combustion space from one pound of wet coal is 10335 B. t. u. The efficiency of the grate may, then, be represented by $10335 \times 100 \div 10706$ 96.53

Combustion Chamber Efficiency—E_c.

Temperature of escaping gases.................... 564 deg. Fah.
Temperature of air and coal entering furnace........ 74 deg. Fah.
Temperature of steam in the boiler.................. 325 deg. Fah.
Average of Orsat readings:

$CO_2 = 8.50$ per cent by volume,
$O_2 = 11.14$ per cent by volume,
$CO = 0.04$ per cent by volume,
$N = 80.32$ per cent by volume.

If we assume equal percentages of carbon and sulphur burned, the correction for the presence of sulphur dioxide may be made as follows

The relative weight of C in CO_2=per cent CO_2 by volume, times 12.

The relative weight of C in CO=per cent CO by volume, times 12.

The relative weight of S in SO_2=per cent SO_2 by volumes, times 32.

The ratio of the weight of carbon to the weight of sulphur may, then, be expressed thus: $12 \times$ per cent $CO_2 + 12 \times$ per cent $CO \div 32 \times$ per cent SO_2; which from Column D above is $0.5592 \div 0.0410$. From the Orsat readings the per cents of $CO_2 + SO_2 = 8.5$ from which the $SO_2 = 8.5 - CO_2$. Substituting this value in the above we

have $\dfrac{12\times\%CO_2+12\times\%CO}{32(8.5-\%CO_2)}=\dfrac{.5592}{.0410}$ from which equation $CO_2=8.27$ per cent; $SO_2=8.5-8.27=0.23$ per cent.

Gas analysis corrected for SO_2 content is then:

$CO_2=$ 8.27 per cent by volume,
$SO_2=$ 0.23 per cent by volume,
$O_2=$ 11.14 per cent by volume,
$CO=$ 0.04 per cent by volume,
$N=$ 80.32 per cent by volume.

100.00

The ratio of the weight of $CO_2+SO_2+O_2+CO+N$ to one pound of carbon can be determined from the following expression:
$\dfrac{700+4\times\%CO_2+9\times\%SO_2+\%O_2}{3(\%CO_2+\%CO)}$, which, when evaluated for this particular case gives........................29.94 lbs.

Moisture in one pound of air........................0.009 lbs.

Useful heat absorbed by the boiler per pound of wet coal..6290 B.t.u.

If we assume that CO as shown by the gas analysis was the only form of incomplete combustion, we may form a heat balance as follows: Calorific value of one pound of wet coal, 10706 B. t. u.

ITEM		B. t.u.
I	Useful heat absorbed by the boiler	6290
II	Heat carried away by moisture from the coal $=0.0966(212-74+966+0.48(564-212))$	123
III	Heat carried away by water formed by the burning of hydrogen $=9\times0.0393(212-74+966+0.48(564-212))$	450
IV	Heat carried away by "dry gases" $=29.94\times0.5592(564-74)0.24$	1969
V	Heat carried away by moisture in the air $=16.37\times.009(564-74)0.48$	35
VI	Heat radiated	572
VII	Heat value of refuse	371
VIII	Heat value of $CO=\dfrac{\%CO}{\%CO_2+\%CO}\times0.5592\times10150$	27
	By difference	869
		10706

The 869 B. t. u. of the last item of the heat balance indicated that CO was not the only form of incomplete combustion; for all of the heat value of the fuel ascending from the grate, i. e. 10335 B. t. u. for every pound of wet coal used, was not developed. This means that the fuel represented by Column D in the above table was not completely burned and therefore Items III and IV of the heat balance may be in error, for they are calculated on the assumption that CO was the only form of incomplete combustion.

That per cent of the heat value of the fuel arising from the grate (10335 B. t. u.) that was actually developed may be called the efficiency of combustion, or the percentage of completeness of combustion. For convenience this efficiency may be represented by E_c. The value of the sum of the heat balance Items III and IV can be closely approximated by multiplying the sum of these items as above computed for the heat balance by the value of E_c.

The accompanying table shows the correct value of the sum of Items III and IV for various conditions of incomplete combustion and also the possible error in B. t. u. that might arise by approximating this sum by the method just stated:

Nature of Incomplete Combustion.	B. t. u. per pound	Real Loss when Ec=100	Estimated Loss 2419	Error in B. t. u.	Real Loss when Ec=95	Estimated Loss 2298 B. t. u.	Error in B. t. u.	Real Loss when Ec=90	Estimated Loss 2177	Error in B. t. u.	Real Loss when Ec=85	Estimated Loss 2056 B. t. u.	Error in B. t. u.
H_2	62100	2419	0		2324		—26	2228		—51	2133		—77
C_2H_4	21465	2419	0		2311		—13	2199		—22	2089		—33
CH_4	23851	2419	0		2302		—4	2184		—7	2067		—11
C	14600	2419	0		2298		0	2177		0	2057		—1

With the Items III and IV corrected, the sum of Items I to VI inclusive represents all the heat that has been generated from one pound of wet coal and this sum multiplied by 100 and divided by the heat value of the fuel arising from the grate (10335 B. t. u.) is the value of the efficiency of combustion. This statement is represented by the following equation:

$$\left(6290+123+\frac{450\,E_c}{100}+\frac{1969\,E_c}{100}+35+572\right)\left(\frac{100}{10335}\right)=E_c.$$

from which the value of E_c is found to be 88.68.

The heat balance as corrected is, then,

Heat value of one pound of wet coal 10706 B. t. u.=100%.

Item.		B. t. u.	Per cent.
I	Useful heat absorbed by the boiler.........	6290	58.75
II	Heat carried away by moisture from the coal	123	1.15
III	Heat carried away by water formed by the burning of hydrogen=$450\times E_c$.........	399	3.74
IV	Heat carried away by the "dry gases"=$1969\times E_c$..........................	1746	16.31
V	Heat carried away by moisture in the air....	35	0.33
VI	Heat radiated	572	5.35
VII	Heat value of refuse....................	371	3.47
VIII	Heat value of unburned gases=$(100—E_c)$ 10335=...........................	1170	10.90
	Total	10706	100.00

Furnace Efficiency—E_f.

The term furnace has come to include not only the grate and apparatus for stoking the coal and releasing the refuse, but to include also the entire combustion space. It is therefore proper to define the efficiency of the furnace as that per cent of the heat value of the wet coal that is presented to the boiler. The sum of the first six items of the heat balance, 9165 B. t. u., represents the heat generated, so we may calculate the furnace efficiency thus:

$$E_f = \frac{9165}{10706} = 85.60.$$

It may also be determined thus: $E_f = E_g \times E_c = 96.53 \times 88.68 = 85.60$.

In the strictest sense of the definition, the heat radiated from the furnace should be subtracted from the total heat generated, but the radiation loss is at best hard to determine and it will be convenient to charge all of it to the boiler.

It will be noticed that the various efficiencies defined deal with heat quantities. The word efficiency, as commonly used by engineers, implies a ratio and indicates that a portion of the quantity with which we are dealing has been lost or otherwise rendered useless. The efficiency of a furnace must not be taken as a measure of its effectiveness, for the function of a furnace is to not only develop all of the heat value of the wet coal but to deliver the products of combustion to the boiler at the highest possible temperature. Thus the idea of an efficient furnace in the sense of its being effective includes both quantity and intensity of heat and cannot be expressed by a ratio.

Boiler Efficiency—E_b.

The boiler efficiency as used in this discussion is defined as the per cent of the heat generated that has been absorbed by the boiler and carried away in the steam. It is calculated thus:

$$E_b = \frac{6290 \times 100}{9165} = 68.63.$$ This efficiency will be used frequently in the latter part of this paper.

It may be well to note the difference between boiler efficiency E_b as here defined and the "boiler efficiency" as given in item 72 of the A. S. M. E. code. There are two ways in which this efficiency as givn by the code is usually determined.

Assuming the following data, these two methods are given:

First Method:

Total weight of dry coal consumed	10,046 lbs.
Total weight of refuse	1,780 lbs.
Total moisture free fuel arising from grate	8,266 lbs.
Total water evaporated from and at 212 deg. Fah	72,413 lbs.
Calorific value of one pound of moisture and ash free coal as determined by the calorimeter	14,252 B.t.u.

$$\text{“Boiler efficiency”} = \frac{72413 \times 965.7}{8266 \times 14252} = 59.36.$$

The "efficiency" as here calculated may be defined as the ratio of the useful heat absorbed by the boiler to the heat that would have been developed, if we assume that:

1st. The heat value of each pound of the moisture free fuel arising from the grate would have been the same as the heat value of one pound of the moisture and ash free coal; and

2nd. That the fuel arising from the grate would have been completely burned.

Second Method:

The fixed carbon plus the volatile matter referred to wet coal is	75.12 per cent
Total wet coal fired	11,124 pounds
Total coal, moisture and ash free used, 11124×0.7512	8,356 pounds
Total refuse	1,780 pounds
"Combustible" in refuse	18.22 per cent
Total "combustible" in the refuse 1780×0.1822	324 pounds
Total "combustible" arising from the grate, 8356—324	8032 pounds

$$\text{Boiler efficiency} = \frac{72413 \times 965.7}{8032 \times 14252} = 61.12$$

This efficiency, as here calculated, may be defined as the ratio of the useful heat absorbed by the boiler to the amount of heat that would have been generated if we assume that

1st. The heat value of one pound of the "combustible" in the refuse was the same as the heat value of one pound of the moisture and ash free coal; and

2nd. That the fuel arising from the grate would have been completely burned.

If the first supposition and only the first of either definition was correct, this item 72 of the A. S. M. E. code would represent the efficiency of the combined boiler and combustion space, E_b times E_c, and if suppositions one and two were both correct, the result would be the same as the boiler efficiency E_b defined above. There can easily be a difference of 14 per cent of the heat value of one pound of wet coal between either of the values of item 72 of the code and the value of the boiler efficiency E_b defined above. For ordinary commercial tests there can be no great importance attached to the value of this "boiler efficiency," Item 72, A. S. M. E. code and as it is very misleading, it should be omitted to avoid confusion.

Efficiency of Boiler and Furnace Combined—E.

The efficiency of the boiler and furnace combined is the efficiency of the whole steam generating apparatus. It may be defined as the per cent of the heat value of the wet coal that has been absorbed by the boiler and carried away in the steam. It is the same as that

given as Item 73 in the A. S. M. E. Code as "The efficiency of boiler including grate." It is calculated thus:

$$E = \frac{6290 \times 100}{10706} = 58.75 \text{ or}$$

$$E = E_g \times E_c \times E_b = E_f \times E_b = 96.53 \times 88.68 \times 68.63 = 85.60 \times 68.63 = 58.75$$

Pounds of Gas Delivered to the Boiler per Hour.

If the combustion of the fuel arising from the grate had been complete, the weight of the dry gas per pound of wet coal would have been .... 16.74 pounds
and the moisture formed from burning hydrogen would have been.................................0.3537 pounds

It has been shown, however, that only 88.68 per cent of the heat value of the fuel arising from the grate has been generated and consequently the actual values of these items are in error. We may greatly reduce this error by assuming that only 88.68 per cent of each of the constituents C, H and S arising from the grate to be burned; on this assumption the weight of dry gases for one pound of wet coal is .... 14.85 lbs.
and the weight of water formed from burning hydrogen is 0.3137 lbs.

The total weight of water in the gases from one pound of wet coal then is:

Water from burning hydrogen........................	0.3137 lbs.
From moisture in the air............................	0.1494 lbs.
Moisture in coal....................................	0.0969 lbs.
Total..	0.5600 lbs.
"Dry Gas" per pound of wet coal......................	14.85 lbs.
Total gas per pound of wet coal......................	15.41 lbs.
Total pounds of gas delivered to the boiler per hour is 1121 × 15.41 or	17,275 lbs.

Heat Available to the Boiler per Pound of Wet Coal.

By available heat is meant the heat in the furnace gases above the steam temperature of 325 deg. Fah.

In the method given here for studying the heat absorbing properties of steam boilers, the exact value of the specific heat of the products of combustion and the fact that this value might materially increase with high temperatures, are of no consequence. It is only necessary that the B. t. u. carried by each pound of gas and the B. t. u. available for raising temperatures are correctly determined. The use of the specific heat may be entirely done away with by substituting for the calculated initial temperature, the number of B. t. u. available for raising one pound of gas from the temperature of the atmosphere to that of the furnace.

In the following calculations, the specific heat of the gas is taken as 0.249 throughout the entire range of temperature. This value is determined thus:

Weight of dry gas in one pound of the products of combustion .... 0.9637 lbs.
Total weight of steam in one pound of the products of combustion .... 0.0363 lbs.

$$0.9637 \times 0.24 = 0.231$$
$$0.0363 \times 0.48 = 0.018$$
$$\overline{\quad 0.249 \quad}$$

It will be convenient to assume that 0.249 is the specific heat of water from 74 deg. Fah. to 212 deg. Fah. and to add to the latent heat of vaporization the additional heat required to raise the 0.0266 pounds of water from 74 deg. Fah. to 212 deg. Fah., thus:

Latent heat in one pound of gas=0.0266×966........25.70 B. t. u.
(1.00—0.249) (212—74) 0.0266.................... 2.76

28.46

Heat in one pound of gases not available for raising temperature .... 28.46 B. t. u.

There are 15.41 pounds of gas for every pound of wet coal burned and 9165 B. t. u. liberated from each pound of wet coal, therefore each pound of gas carries, initially, 9165÷15.41, or 595 B. t. u.

This 595 B. t. u. may be divided as follows:

Latent heat 28.46
Heat to raise the temperature from 74 F. to 325 F. (325—74) 0.249 .... 62.50 B.t.u.
Heat above boiler temperature 325 F. (by difference) . . 504.04 B. t u.

Total.. 595.00 B. t. u.

The total heat available to the boiler per pound of wet coal is 15.41×504.04=7767 B. t. u. This is 84.75 per cent of the heat that was generated.

Calculated Initial Temperature.

The 504.04 B. t. u. in one pound of gas above 325 deg. Fah. will raise the temperature of the gas 504.04÷0.249 or 2024 deg. Fah. The calculated initial temperature is, then, 2024+325=2349 deg. Fah. The calculated initial temperature is higher than the actual furnace temperature for the following reasons:

1st. The specific heat of the gases at these high temperatures is probably higher than 0.249.

2nd. Heat is absorbed by the boiler before combustion is complete.

3rd. Heat is radiated from the furnace.

True Boiler Efficiency, E_t.

In the boiler efficiency E_b as defined above, a condition is imposed which prevents the boiler from ever having an efficiency of 100. To be perfectly fair to the boiler builder we may express the heat absorbed as a per cent of the heat available, thus:

$$E_t = \frac{6290 \times 100}{7767} = 80.98$$

This per cent has been called the true boiler efficiency for the reason that it is a better measure of the boiler's effectiveness. Since $E_t = E_b$ divided by the available heat expressed as a per cent of the heat generated, we may get an idea of the dissipation of the heat value of one pound of the wet coal from the following:

$$E_g \times E_c \times 84.75 \times E_t = E \text{ or}$$
$$96.53 \times 88.68 \times 84.75 \times 80.98 = 58.75.$$

DETERMINATION OF THE VARIOUS WAYS IN WHICH A GIVEN CAPACITY MAY BE DEVELOPED.

Referring to Chart 1, AB and CD are two rectangular axes intersecting at Q, the ordinates represent temperature and the abscissae the number of pounds of gas delivered to the boiler per hour.

The origin Q represents the point of zero pounds of gas per hour

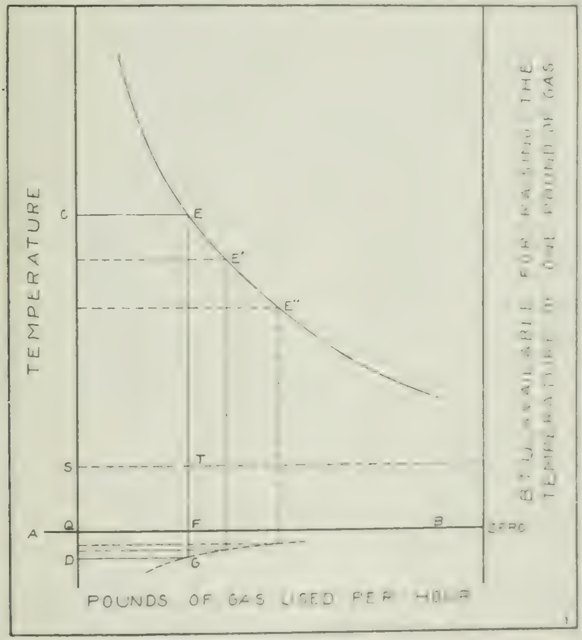

Chart 1

and the temperature of the atmosphere=74 deg. Fah. We may plot on these two axes the two furnace conditions of the above test, which determine the heat absorbed by the boiler per hour. In this, QF represents the 17,275 pounds of gas delivered from the furnace to the boiler per hour and FE represents the calculated temperature, 2349 deg. Fah. The position on the chart of the point E fixes the amount of heat absorbed by the boiler per hour which was $1121 \times 6290 = 7{,}051{,}090$ B. t. u., or the equivalent of 210 boiler horse power. This means that every time the furnace delivers to this particular boiler 17,275 pounds of gas per hour, at a temperature 2349 deg. Fah., the boiler will develop 210 B. H. P.

Experiments have demonstrated that this same capacity can be developed by a lower temperature than 2349 deg. Fah., provided the number of pounds of gas delivered to the boiler is increased; in other words, points E′ and E″ also represent furnace conditions which will cause the boiler to develop 210 B. H. P.

The line of uniform capacity E, E′, E″, can be determined by conducting eight or nine tests, all run at the same capacity, 210 B. H. P., but each differing from the others in the number of pounds of air used per pound of coal, and plotting the furnace conditions of each test on the chart as has been done in the example given.

The idea of developing a chart similar to that of Chart 1, occurred to the author while he was employed by the Government as data observer on the tests made by the U. S. Geological Survey at St. Louis, in 1905, and he determined to try out this scheme on these St. Louis tests. The data from these tests was not well adapted for the work at hand, for to accurately determine constant capacity curves such as E, E′, E″, the following four conditions should exist:

1. Uniform feed of fuel to the furnace is the most important one to be observed. In the case of hand-fired furnaces, it is impossible to get a representative sample of the stack gases because the rate of gas production in the furnace is exceedingly variable, due to the opening of the fire doors and to the rapid and intermittent volatilization. Now the composition of the gas changes quite as much as does the rate of gas production and these two changes occur at the same instant, so in order to get a correct sample of gas, the rate of drawing the sample from the stack must change exactly as the rate of gas generation and these two rate changes must occur simultaneously. Needless to say it is impossible to even approximate these conditions. The error arising from this source is much greater than may at first thought be supposed.

2. A self-cleaning stoker should be used so that the conditions of capacity and furnace temperature may be kept from varying. A chain grate would be well suited to this work.

3. A means should be provided to determine the amount of heat radiated per hour.

4. A uniform fuel should be used for every test in order that (a) the specific heat of the gases will be kept as nearly as possible the same in every instance; (b) the latent heat in the gases from one

pound of coal will be as nearly as possible the same in every instance; (c) the efficiency of the grate and the completeness of combustion each be kept as high as possible.

Now, not one of these four conditions existed in the St. Louis tests. They were made with a hand-fired furnace. The capacity and furnace temperatures varied materially during any one test. No provision was made to regulate or determine the amount of heat radiated. Usually only two or three tests were made on the fuel from any one mine.

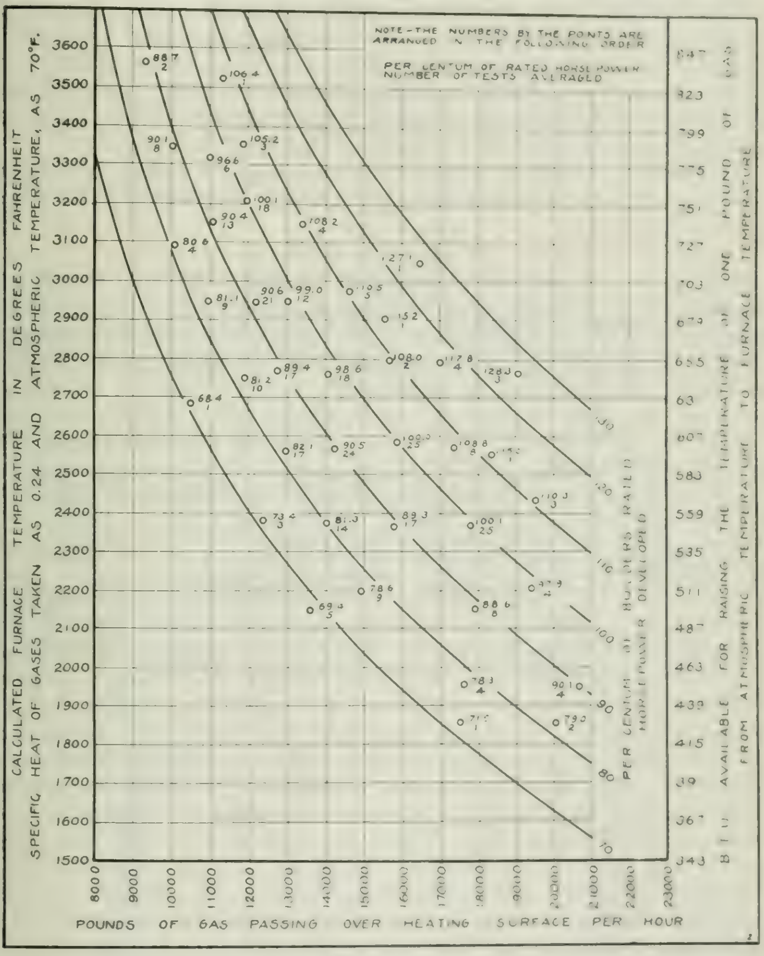

Chart 2

In addition to these variable conditions, the data on stack temperatures for at least one-half of the tests are considered by the author to be seriously in error. There was no ultimate analysis made

of the refuse. There were at hand, however, the data for quite a number of tests, so the various things which would in individual tests cause the location of point E, Figure 1, to be in error, were partly overcome by the following scheme: If there were, say, six tests found that were all nearly the same with respect to capacity developed, calculated initial temperature and pounds of gas used per hour, the data for these six tests would be averaged and the various averages considered as data from one representative test. In this way the 355 actual tests were reduced to 40 representative tests. When the data from these 40 representative tests were plotted the result was quite gratifying. Chart 2 shows the point E of Chart 1, located for the 40 representative tests and the lines of uniform capacity drawn through these points. The numbers by the points indicate the number of tests averaged for a representative test and the average capacity developed expressed in per cent of rating.

In order to determine with considerable accuracy the lines of uniform capacity, their analytical equations have been determined. Their general form is

$$(y-61)^n . x = k$$

where y=B. t. u. available for raising the temperature of one pound of gas; x=pounds of gas used per hour, and n and k are arbitrary constants. The locations of all of the 40 points have been used to determine each line of uniform capacity by expressing both n and k as functions of the capacity developed.

Having given the various ways in which known boiler capacities may be developed, to determine

1st. With any given capacity what effect different furnace temperatures will have on the boiler's efficiency E_b.

2nd. With any given furnace temperature what effect increasing the capacity of a boiler will have on its efficiency E_b.

The points in Chart 2 could each be numbered with the efficiency E_b with which their representative tests were run and lines of uniform boiler efficiency E_b located. But in order to determine the lines of uniform efficiency with a greater degree of accuracy, a more elaborate scheme has been used. On the right side of Chart 1 is the scale showing the B. t. u. that is available for raising the temperature of one pound of gas. It was shown in the calculations for the test given that in addition to the heat available for raising temperature there was for every pound of gas the equivalent of 28.46 B. t. u. of latent heat of evaporation. Using the scale to the right (of Chart 1) we may lay off F G equal to this 28.46 B. t. u. so that E G will represent the total heat in one pound of gas and since C E represents the number of pounds of gas used per hour, the area C E G D represents the amount of heat generated in the furnace per hour.

With a given fuel and uniform conditions of completeness of combustion, the equivalent latent heat of vaporization in the gases is a given fixed per cent of the total heat generated, so that the distance F G always bears a fixed relation to the distance F E; in the example given

$$\frac{F\,G}{F\,E} = 0.05, \text{ so that } F\,G + F\,E = 1.05\,F\,E$$

The total heat developed in the furnace per hour may then be expressed thus:

$$\text{Area } C\,E\,G\,D = 1.05\,xy$$

Now, the heat absorbed by the boiler per hour is a constant for any point along a given uniform cap curve, so that if we represent this quantity of heat by H, we may write

$$E_b = \frac{H \times 100}{1.05\,xy}$$

But from the equation of the uniform cap curves

$$x = \frac{K}{(y-61)^n}$$

Substitute this value in the above, we have

$$E_b = \frac{H\,100\,(y-61)^n}{1.05\,K\,y}$$

As H, K and N are constants for any given capacity, the above expression states that there is a definite relation between the boiler efficiency E_b and the furnace temperature when any one capacity is considered. The expression is an empirical formula in the sense that it is not derived from theory but gives the relation as has been determined by actual performance.

Different values have been assigned to Y in this equation and the corresponding boiler efficiency E_b calculated. This was done for each of the 7 curves of uniform capacity shown in Chart 2.

To illustrate: It was found that when the boiler developed 70% of its rating the following relations as determined by this equation existed:

Assigned values of y	Corresponding calculated values of E_b
1640	61
1710	62
1780	63
1850	64
1925	65
2005	66
2085	67
2180	68
2265	69
2365	70
2480	71
2625	72
2780	73
2970	74

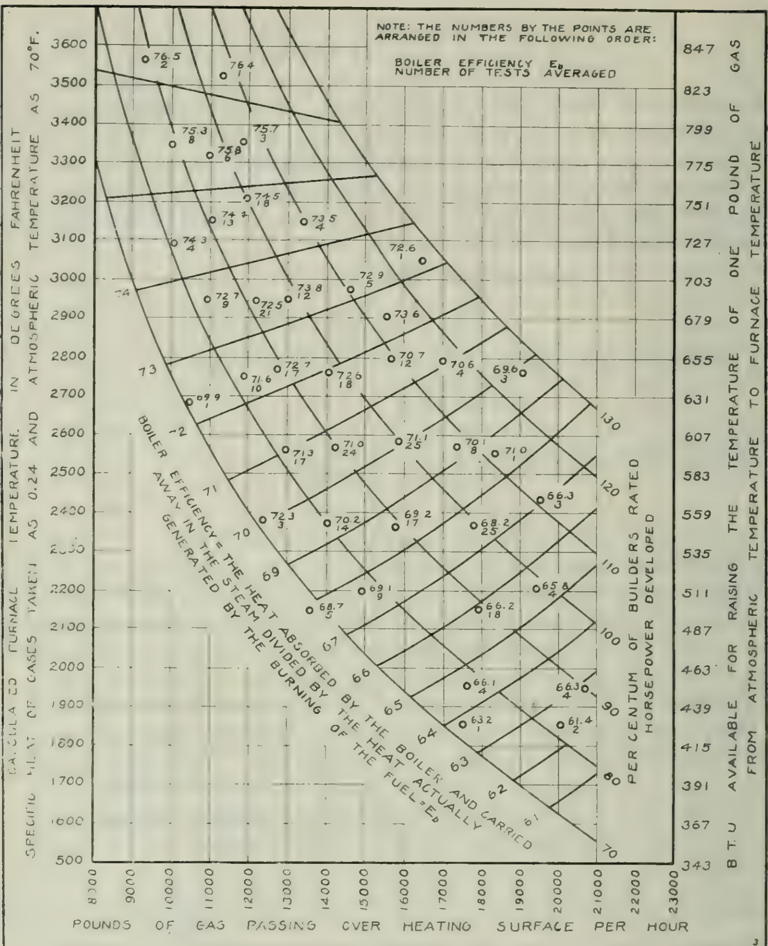

Chart 3

The relations thus calculated have been shown graphically in Chart 3, points along the curve of 70% capacity being located whose initial temperatures were 1640, 1710, 1780, etc., and these points labeled with their corresponding values of E_b.

Similar points were located for all seven uniform cap curves and curves of uniform boiler efficiency drawn through points that were alike in their value of E_b.

Chart 3 is the same as Chart 2, except that the lines of uniform E_b have been added and the numbers by the 40 points, indicate the E_b which was calculated from actual data and the number of tests averaged.

It is to be noted that the positions of the 40 points on these charts

were determined by knowing what happened in the furnace, and from these data one may, by the point's position on the chart, determine very closely what are the boiler capacity and the boiler efficiency E_b.

Of the 40 representative tests plotted, the difference between the capacity as calculated in the usual way and the capacity as determined from the point's position on the charts, is

For 20 tests, less than 1% of rating,
For 13 tests, between 1% and 2% of rating,
For 5 tests, between 2% and 3% of rating,
For 1 test, between 3% and 4% of rating,
For 1 test, between 4% and 5% of rating.

The difference between the E_b as calculated and the E_b as determined from the chart is

For 28 tests, less than 1% of the heat generated,
For 7 tests, between 1% and 2%,
For 4 tests, between 2% and 3%,
For 1 test, between 3% and 4%.

It is the author's opinion that if the 4 ideal test conditions which have been set forth above for determining these charts had existed, the location of point E should, for each individual test, have come within less than one per cent of its allotted position.

When the author first attempted to establish a relation between the heat absorbed by the boiler and the furnace conditions, the significance of the unaccounted for loss which appears as Item VI in the heat balance of the A. S. M. E. Code was not well understood by him and consequently all calculations were made on the assumption that, aside from the C O loss, combustion was complete. On this assumption, the boiler efficiency defined in the code under Item 72, became that per cent of heat generated that was absorbed by the boiler. There was little success obtained on this basis and there was no regularity about the locations of the points. This fact, that there is not a well defined arrangement of the points until incomplete combustion was taken account of, should be taken as convincing evidence that there are often losses due to incomplete combustion, which losses cannot be determined from the analysis of the escaping gases, and that the method set forth in this paper for determining the amount of this loss is quite accurate and practical.

WHY INCREASING CAPACITY AFFECTS THE BOILER EFFICIENCY IN THE MANNER SHOWN BY CHART 3.

It is shown in Chart 3 that at a calculated initial temperature of 3300 deg. Fah. the boiler absorbs 75.3 per cent of the heat generated, irrespective of the capacity being developed. At lower temperatures than 3300 deg. Fah. the boiler is more efficient when run at the lower capacities; for instance, with an initial temperature of 2000 deg. Fah., the boiler absorbs about 72 per cent of the heat generated when developing 70 per cent of rating and only 67 per cent of the

heat generated when developing 130 per cent of rating. For initial temperatures above 3300 deg. Fah. the boiler is actually more efficient when developing the highest horse power.

With an initial temperature of 3300 deg. Fah., there is ten per cent of rating developed for each 1150 pounds of gas used per hour. If we neglect the heat absorbed by the setting, or assume that the heat absorbed by the setting is proportional to the amount of heat absorbed by the boiler, the final or stack temperature will be the same for all capacities, when the initial temperature is 3300 deg. Fah., for the boiler efficiency is the same for all capacities. Under these conditions of equal initial and equal final temperatures, the velocity of the gas through the boiler is directly proportional to the mass of gas used per hour and consequently the time that any unit mass of gas is under the cooling influence of the boiler is inversely proportional to the velocity, or to the mass of gas used. These conditions are shown graphically on Chart 4, for different values of the number of pounds of gas used per hour.

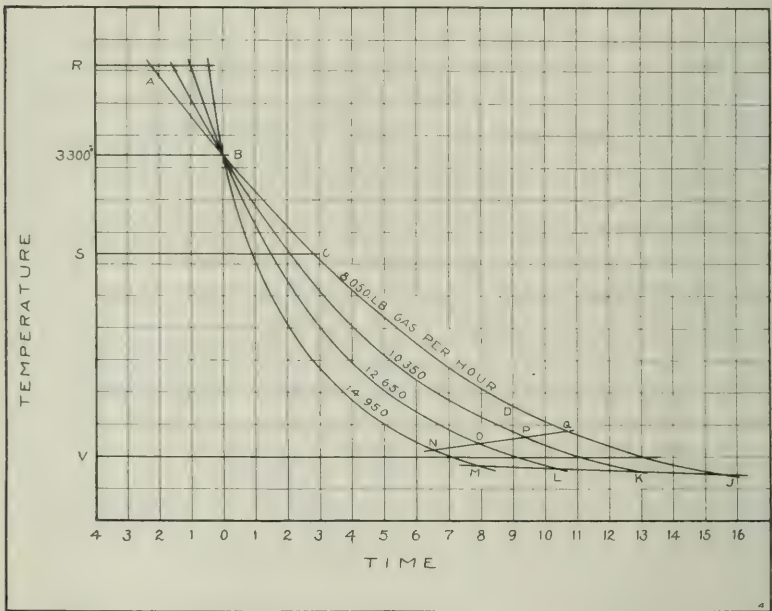

Chart 4

The curve A B C D represents the law of cooling of a unit mass of gas when 8050 pounds are used per hour; the gas enters the boiler at a temperature of 3300 deg. Fah., is under the cooling influence of the boiler for 13 units of time and leaves at a temperature V. As the number of pounds of gas used per hour is increased from 8050 to 10,350, 12,650 and 14,950 the velocity of the gas increases in the same ratio, viz.: 7-9-11-13 respectively, and consequently the time

that any unit mass of gas is in the boiler decreases in the ratio of 13-10.1-8.3-7 respectively. It is evident that as the time element decreases, the rate of cooling increases sufficiently, to bring the gas down to the same final temperature V in each case. The exact way in which this rate of cooling is increased is so complex and intangible that it is difficult to arrive at any perfectly satisfactory explanation. The following one intended to be free from the mathematical considerations, is offered as an explanation for the form of Chart 3 and while it is simple, it is liable to criticism for the reason that it is too abbreviated.

Let us consider that on the fire side of the tube there is a layer of soot or gas, or whatever you may please, and that this layer is always of just enough thickness to offer a definite, though exceedingly small, amount of resistance to the flow of heat, and that whatever may happen to succeeding layers, this one of definite resistance is never removed.

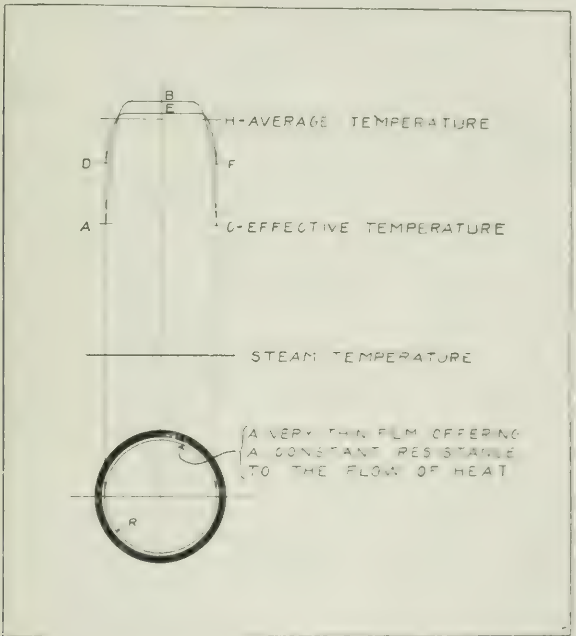

Chart 5

In Chart 5 is shown what the temperature of the gas through a section of a fire tube might be. That part of the gas nearest the cooling surface is naturally of lower temperature than the gas in the center of the tube so that the temperatures along a diameter may be represented by some such a curve as A B C. Now the transfer of heat through the medium of this film and the tube to the water can only take place when there is a difference between the tempera-

ture of the fire side of this medium and the temperature of the water, and the rate at which this transfer will take place increases as the temperature difference increases. The average temperature of the moving gas at any point along the tube may be represented by H (Chart 5), but the temperature which will determine the rate of heat transfer through the film of definite resistance is the temperature C which may be termed the effective temperature. The difference between the effective temperature C and the temperature of the water is, then, the only motive force which causes the transfer of heat, and it seems wrong to reason that the velocity of the gas is in itself such a force.

The effect of increasing the velocity of the gas is to flatten the curve A B C to D E F (Chart 5), and while the average temperature H has not been disturbed, the effective temperature has been increased from C to F and consequently the rate of transfering the heat has been increased. The flattening of curve A B C to D E F may have been accomplished by friction having caused some inert gas near R to have been removed and thus having lessened the resistance from the point R to the center of the tube. Or it may have been brought about by the increased axial velocity of the gas giving particles near to R a radial component of motion and thus equalizing the temperature by convection.

For the boiler that Chart 3 refers to and with an initial temperature of 3300 deg. Fah., the net effect of the increased velocity on the effective temperature is to increase the average rate of cooling just enough to compensate for the shortening of the period of time in which the gas has a chance to cool, so that a constant boiler efficiency occurs for all capacities at this initial temperature.

When the gas enters at the lower temperatures, the average volume is less and the resulting velocity will be slower and the time some longer than when the initial temperature was 3300 deg. Fah. However, the difference in the time factor will be very slight, so for convenience it will be assumed, that regardless of the initial temperature a unit mass of gas is subject to cooling for 13 units of time when 8050 pounds of gas are used per hour.

What happens when the initial temperature is less than 3300 deg. Fah. is shown in Chart 4. According to the law of cooling A B C D, the gas when entering at the temperature S below 3300 deg. Fah., will in 13 units of time be reduced to temperature J. Similarly the temperatures in cases of increased velocity will be reduced to K, L and M. It is seen that under these conditions of initial temperatures below 3300 deg. Fah., what is gained by increasing the effective temperature, by increasing the velocity, is not sufficient to make up for what is lost by reducing the period of time that the gas is in the cooling region and therefore the temperature is reduced the lowest, where the time element is greatest, i. e., where a small amount of gas is used per hour, and consequently for temperatures below 3300 deg. Fah. the boiler's efficiency is the highest when run at low capacity.

If the gas enters at a temperature R above 3300 deg. Fah., and the periods of time of 7, 8.3, 10.1 and 13 units, are laid off on the four curves, Chart 4, the resulting final temperatures are Q, P, O and N. Here there is more gained by the good effect of the increased velocity on the effective temperature than is lost by the shortening of the time element and as a result the highest efficiency occurs where the velocities are highest, that is at the highest capacities.

By increasing the velocity of the gas there are then, two factors arising which affect the final temperatures. One of these factors, the time consideration, operates to *Raise* the final temperatures with increased velocity by diminishing the period of time that the gases have to cool. The other factor, that tendency to increase the effectiveness of the heating surface, operates to *Lower* the final temperatures and this factor is more pronounced at high temperatures than at low ones. Then the explanation of the form of Chart 3 is, that for low initial temperatures and increasing velocity the effectiveness of the cooling surface does not increase rapidly enough to compensate for the shortened time period and therefore the boiler is more efficient when run at low capacities, but as the initial temperature becomes higher the tendency of the increasing velocity to increase the effectiveness of the cooling surface becomes more pronounced, which fact accounts for the lines of uniform boiler efficiency becoming more nearly horizontal. Eventually an initial temperature

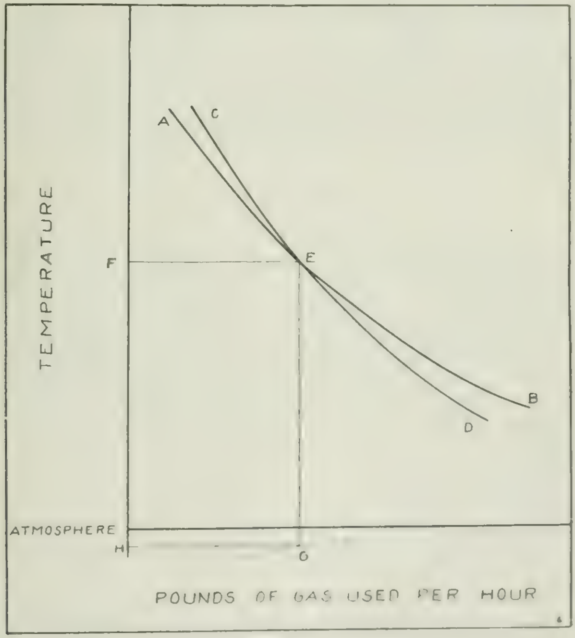

Chart 6

is reached at which the increasing velocity increases the effectiveness of the heating surface sufficiently to compensate for the shortened period of time and the boiler's efficiency is the same for all capacities. Above this temperature what is gained by increasing the effectiveness of the heating surface, by employing higher velocities, is more beneficial than the accompanying shortening of the time period is detrimental and therefore the highest efficiencies occur with the highest velocities and capacities.

A PRACTICAL USE OF CHART 2.

These lines of uniform capacity, Chart 2, should be of some service in the developing of an efficient boiler. Suppose, for instance, that there is a boiler well adapted for either the horizontal pass or vertical pass and it was desired to determine which method of baffling would make the boiler the more efficient. It would be necessary to make, say eight tests, using the horizontal pass. Each of these tests must be run at the same capacity, but each with a different per cent of CO_2 in the escaping gases. This will furnish enough data to establish the uniform capacity line. Let us suppose A E B, Chart 6, to be such a curve. The baffling may now be changed and the tests duplicated in order that the uniform capacity line may be established for the vertical pass. It is very possible that some such a line as C E D will result. Remembering that the area F E G H represents the heat generated for tests represented by E, we know that at a temperature represented by F one scheme is just as efficient as the other. At higher temperatures than F the horizontal scheme becomes the better one and at temperatures below F the vertical scheme is best. Results thus plotted give a definiteness which cannot be obtained by mere comparison of calculated efficiencies.

Discussion.

Mr. W. L. Abbott, Chairman: There was an old riddle that went round when I was a boy; it ran something like this: "What fish has its eyes nearest together?" The answer was, "The smallest." Here is an engineering riddle: "Given a furnace with a constant rate of combustion of fuel, and a certain efficiency, what is the best size of boiler to set over that furnace?" The answer is, "The smallest." That at least is as I understand the main proposition advanced in this paper. As we usually say in such cases, "remarkable if true."

Mr. A. Bement, M.W.S.E.: To me the most important feature of the paper is the effort made to take into account the loss in escaping hydrocarbons and smoke due to incomplete combustion, something which is too often neglected or excluded from consideration.

It is stated that with constant high furnace temperature, efficiency secured with the boiler increases with capacity developed, yet we know both by experience and reasoning that this cannot be

true. One cause for this apparent result may be found in the larger amount of water escaping from the boiler with the steam in the type of apparatus used by the United States Geological Survey in the various coal tests, data from which has been employed by the author in his paper.* At high capacities a large quantity of water not shown by the calorimetric determination may escape in this way, and yet be considered as having been evaporated.

The variation between the efficiency of two different boilers is at a minimum with high initial temperature, and at a maximum with low, but the highest efficiency is always obtained with the best boiler, initial temperature being equal for each. Thus the curves would not cross as indicated in Fig. 6, but approach each other at high temperature, and diverge as the initial temperature decreased.

In reference to "furnace efficiency," it would appear that if the fuel is completely burned, it would be considered as a condition of 100% efficiency. This is true as far as the mere burning of the fuel is concerned, but a fire is made under a boiler only for the purpose of heating its contents, and if the air supply is in excess, it necessarily follows that the temperature is proportionately low, with the result that less heat passes to the boiler than if the temperature were higher. Thus no definition of "furnace" or efficiency of combustion can be correct which neglects temperature.†

Were we to test boilers in an ideal manner,‡ it would require some standard fire condition, as great complication and difficulty are introduced by different characters of fuel, kinds of furnaces, variety of stokers and fire grates, as well as irregularity in manipulation. In this connection, Mr. Ray has mentioned to me a scheme proposed to eliminate these variable influences. It consists, for example, in passing a constant quantity of air through two boilers to be compared, both under the same steam pressure supplied from a third, and the boiler heating its air to the highest temperature is the best, or in other words, the most efficient.

Walter T. Ray, M.W.S.E.: Before beginning my discussion I wish to say that altho I am an employee of the Technologic Branch of the United States Geological Survey, my participation in this meeting is entirely unofficial, and does not in any way commit the Survey, notwithstanding that the information I am to give has been obtained by the Survey, and is to be credited to it.

I am thoroly in sympathy with Mr. Stowe's implication in his introduction that our knowledge of heat impartation from hot gases to boiler-water is inexcusably crude. I agree that "we can by going beyond the usual calculations arrive at data which may at least introduce us into this field of investigation." I regret that so excellent a paper, so full of good substance, has not been more

*Trans. Am. Soc. Mech. Eng., Vol. XXVI, p. 312.

†Trans. Am. Soc. Mech. Eng., Vol. XXVI, pp. 418 and 619.

‡Jour. W. S. E., Vol. VI, p. 231.

clearly written, altho it would be longer; nevertheless I am very confident that a careful study of it will repay any one.

To me there is a fundamental fault with Mr. Stowe's line of calculation, which is inherent in any such attempt based on so-called "boiler tests"—it is impossible even approximately to separate the heat absorbed by radiation and conduction from that absorbed by convection. His method avoids the attempt but misses some of the benefits which would come from a separation. How, then, can a separation of these three heat supplies to a boiler be effected, so as to enable us to improve future designs in each of these three respects and to modify existing installations? For instance, how can we find out whether cross-baffling a boiler of the parallel-flow type, causes it to absorb more or less heat from the gases at any and all rates of working? So far as I know no accurate easy method has been published, either mathematical or experimental. The one I am about to offer is still in the trial stage, and while it requires careful manipulation and very accurate thermometers, I believe it will prove far less expensive and more reliable than any method heretofore devised. Nevertheless if any one should try it on one of his boilers and find it wrong or impracticable, it is distinctly stated now that neither the present speaker nor the U. S. Geological Survey is to be blamed. The method is offered half-developed, because it is thought to be valuable and because the speaker and his co-workers shall not have time to develop it for several months, if at all.

Suppose it be desired to determine which of two boilers is the better heat absorber in its gas passages, where all absorption is due solely to the contract of the hot gases with the boiler metal; it being further granted that the furnaces, stokers, tile-roofs, etc., are identically alike in design, material and dimensions. Now it is evident that the heat absorbed by radiation and conduction from the furnaces will be exactly the same in the two cases, under the same fire conditions; and any higher efficiency of either must be due solely to the fact that it absorbs more heat from the gases by convection, that is, by contact.

If boiler A, cools hot gases more than boiler B, at any rate of flow of gas thru it, it should, under similar circumstances, heat up cold gas more than boiler B, when cold gas is sent thru it while it is filled with hot water. Then here is the method of operation of a test very simple in principle—keep hot water circulating rapidly in a boiler by external means (as by jets of entering steam), and blow air through it by fans, measuring the entrance and exit temperatures of the air to and from the boiler.

Assume that the boiler water is kept in rapid circulation at a temperature of 300 deg. F.; assume further that the temperature of the atmosphere is 100 deg. F. On first starting the fan slowly, air will leave the boiler at a temperature of nearly 300 deg. F.; if its rate of movement thru the boiler were extremely slow, and no heat what-

ever were lost thru the setting, and there are no air leaks, the air might even leave the boiler at 200 deg. F. As the fan is speeded up slowly, the flue temperature will drop, rapidly at first, then more and more slowly, until finally it will fall very little with successive increases of fan speed. In some instances this approximately horizontal portion of the curve will never be reached, because the fans will not be able to force enough air thru their boilers.

Suppose that in the cases under discussion, using boilers A and B, the final, steady, exit temperature of the air becomes about 250 deg. F. with boiler A, and 200 deg. F. with boiler B. Now, if both boilers were perfect they would heat the air from 100 deg. to 300 deg.—an elevation of 200 deg.; boiler A heats the air to 250 deg.—an elevation of 150 deg. out of a possible 200 deg., and its true boiler efficiency is therefore $150 \times 100 \div 200 = 75\%$; boiler B heats the air only to 200 deg. F., an elevation of 100 deg. out of a possible 200 deg., and its true boiler efficiency is therefore $100 \times 100 \div 200 = 50\%$. This true boiler efficiency is the same true boiler efficiency as has been used by the U. S. Geological Survey for two years, and designated by it as E_4; it is nearly the same true boiler efficiency as Mr. Stowe designates E_1. The credit for the original conception is due to Prof. John Perry.

The method above proposed is very flexible; for instance, on a very hot day the boiler can be filled with ice water, and the temperature kept down by the continued addition of crushed ice thru an opening in the top of the boiler. The problem would then be to determine the lowering of air temperature effected by the boiler; whether this would be practicable I do not know; but I do know that other and all methods are worth trying because if successful they will put real boiler testing without coal or fire on such a simple basis as has never even been hoped for.

As an example in the ice-water method, suppose that the fans are running at sufficient speed to make the exit-air temperature substantially stationary when the speed of the fans is varied considerably. Assume that the temperature of the boiler water is 35 deg. F., that of the entering air 85 deg. F.; then the greatest possible reduction of air temperature which could occur (with a perfect boiler) would be 85 deg. minus 35 deg., which is 50 deg. Boiler A, having a true boiler efficiency of 75%, would reduce the air 75% of 50 deg., or 37.5 deg. below 85 deg., that is, to 47.5 deg. F. But boiler B, having a true boiler efficiency of only 50%, would reduce the air temperature 50% of 50 deg., that is 25 deg., or to 60 deg. F.

It will be immediately apparent that the temperature ranges of these methods are narrow. This narrowness is of advantage in reducing radiation losses from the setting, etc.; it is of greater disadvantage, in resulting in the introduction of relatively large errors into the answers arising from small errors in temperature measurements. *All* thermometers must be very carefully calibrated to fractions of a degree, in the same oil bath, thoroly stirred. Many

thermometers must be used to take the water temperatures at many points adjacent to the heating surface, and a number of other thermometers be used to get entrance and exit temperatures of the air. All this sounds complicated, and the procedure does in fact require much judgment, but it will be found easier than expected, as the author can testify from personal experience.

This method also lends itself to an investigation of the best methods of baffling a boiler, even before it leaves the maker's shop. A boiler can be enclosed in a fairly air-tight wooden casing (instead of in a brick setting), and the baffles among the tubes can be made of thin wood or even of heavy flexible pasteboard, which can be replaced in a short time by other baffles placed otherwise. When using so-called "forced draft," extreme care need not be taken to have the wooden casing air-tight because leaks will be outward; but the baffles should always fit at least as tight as will the permanent fire-proof ones.

It must be distinctly remembered that this method is a test only for heat absorbed by convection from the gases moving thru the boiler, and supplies absolutely no information as to the other amounts of heat absorbed by radiation and by conduction, which in most types of boiler constitute a very large fraction of the total heat absorbed. But if we can rely on the indications of the experiments already performed, the application of this method will supply for the first time accurate comparative data as to which of two boilers will have the lowest flue temperature; or as to how changes in the arrangement of baffles will effect flue temperatures.

The weak point of this method is that there is no easily applicable way of measuring the amount of air put thru the boiler. The best indirect way of which I know is to measure the heat (or cold) added to the boiler water, in the first method by metering the steam added by a Sargeant or other accurate steam meter, and in the second method by weighing the cruched ice added. Other temperature and draft measurements not here enumerated must be carefully taken.

Whatever modification of the method be used, one must be sure that the water circulate sufficiently to keep its temperature the same in all parts of the boiler.

No fear need be had that the tube metal will be much hotter or cooler than the water, as some measurements made by the Geological Survey in a boiler under heavy firing indicated that the tubes when free from scale were never more than 15 deg. F. hotter than the water scrubbing them. This statement does not apply to blistering conditions, which are abnormal.

In conclusion, I wish again to say that the above-described *experimental method of determining a boiler's true efficiency* is not offered as a criticism of Mr. Stowe's paper, or as a substitute for his method, but as a supplement.

R. H. Kuss, M.W.S.E.: In the paper presented by Mr. Stowe we find the first careful examination and rational application of a great

deal of data that were collected in the Boiler Division of the U. S. Geological Survey Fuel Testing Plant. This, in itself, is no small achievement, and if the writer of the paper had not assumed that his readers are capable of understanding the subject without detailed explanatory matter, there is no doubt but that his contribution would be looked upon as a considerable advance over the literature heretofore bearing on the subject. Even as it is, the more careful students will make a great deal out of it in time.

Without attempting to supply the explanatory matter, a duty which is best fulfilled by the author himself, it may be well to point out the meaning and scope of an investigation of this character.

Heretofore, engineers have been content to conduct boiler trials according to a more or less definite routine, whether the object of the tests happened to be more closely connected with a determination of the influences of the heat absorber, or to study the heat generating phenomena. Attempts to separate the two performances have been exceedingly rare and the usual justification for the unification of the two processes has been to assert that inasmuch as the over-all or combined result is the thing actually employed, no good purpose would be served by a separation of the boiler or heat absorber, and the furnace or heat generator.

The result has been that when the intention was to investigate the boiler particularly, all differences appearing in the general results of several trials have been charged to the boiler, the furnace performance being looked upon as a more or less fixed proposition. Exactly the reverse reasoning obtained if the furnace was subjected to particular investigation. It is to be said, however, that during late years, more attention has been given to furnace performance, and with it a growing tendency that the only changeable factor is the furnace.

So while the author does not lay down a new set of data to be obtained in a boiler trial, by showing a more comprehensive scheme of computation, he is enabled to attack either a boiler discussion or a furnace discussion with equal facility.

The author not being satisfied to accept the usual conclusions, attempts to separate the heat generation from the heat absorber, and manages to find relations as between heat delivery and heat absorption which are graphically set down in Chart 3. While, then, his paper deals essentially with the heat absorber, it is to be remembered that his methods, if found sound, have no less a bearing upon heat generation problems. This is reflected in the paper by the fact that the author was forced to define the meaning of furnace efficiency.

It will be noted that he confines his definition to quantities only, leaving the intensity factors out altogether, though he is bound to and does acknowledge that for the same quantities of heat generated, the ones involving the greatest intensities are the most useful. An analogous case can easily be called to mind, remembering that though boilers delivering high pressures may be the most effi

cacious in the sense that the resulting engine efficiencies are somewhat higher, or, in other words, the steam of higher pressures being more useful or economical, strictly speaking, it is not feasible to take into account the intensity factor in the expression of boiler efficiency. No confusion arises from this arrangement, since the intensity factors are taken up successively anyway, but only in so far as they affect quantity factors.

Another important idea advanced is that all calculations are based upon that portion of the fuel which is gassified or vaporized. Necessarily, this means the starting place should include the moisture of the fuel. For all practical purposes, computations based upon moisture free fuel do not contribute information not found by the wet coal basis.

The author's speculation on the reason for the maintenance of boiler efficiency at approximately uniform figures irrespective of the rate at which the heat is supplied to the boiler, is decidedly interesting but not convincing. In brief, his theory on the subject is essentially that the assumption is made that any heat transference is solely a function of the difference of temperatures between the two media and the time the two media are intimately adjacent; all such factors as contribute to the effective difference of temperatures and the time, are not to be considered as prime causes for maintaining or changing rate of heat transference, but as causes for changing differences in effective temperatures and differences in time. As an example, a difference in velocity of the gas should not be held to be a cause for difference in rate of heat transference only in so far as by a scrubbing effort it affects the gas temperature where it can be effective, i. e., close to the heat absorber. Now, the greater the velocity, the less time any unit quantity of heat carrying medium has to act, and the inference is that if the final result is that a short period in contact does not materially decrease the percentage of heat transferred, the decrease of contact time is very nearly offset, exactly offset, or more than offset by the scrubbing action of the more rapidly moving gas, depending upon whether the boiler efficiency is a little less, equal or greater than for the case of longer contact time.

To list several of the contributory factors affecting the amount of heat transference, assuming two media of different temperatures in contact, we have, including those mentioned by the author:

1. Difference in temperature.
2. Time.
3. Character of contact.
4. Area of contact.
5. Character of the media.

The author, dealing with one difference between the steam temperature and gas temperature, and considering different quantities of gas, assigns correspondingly different volumes to the gas. The inference is, then, that if the gas is to be delivered it must travel

more rapidly for the higher quantity; the velocity, then, is correspondingly higher, and consequently the time in contact is less. As a matter of fact, it does not follow that the velocity increases as the volumes delivered, it being well known that the greater the volume of gas delivered the greater the space employed in traveling through the boiler setting. This means as well that the area of contact is correspondingly greater and the time in contact is not inversely proportional to the volume of gas delivered. Should the maintenance of efficiency occasion as much surprise as the paper indicates?

To be absolutely fair to the author, there is a much better agreement with the proposition he lays down, than is indicated on Chart 3, for there it appears that for the higher heat deliveries there is a drop in efficiency, not as much as is to be expected by assigning less time in contact, but a fall nevertheless. This fall may be accounted for in part by considering that as the heat transference increases, the character of the heat absorbing medium changes because of entrained steam bubbles with less heat absorbing ability than solid water, an ill effect that is partially overcome by easy water replacement or "good circulation." It is to be expected that in this connection the author can point out the analogy between the happenings on the gas side and the water side, of the boiler tube surface, but there is a difference. The character of the medium changes on the water side without a change in temperature, while on the gas side no such change takes place unless by a change of density of the gas.

It is gratifying to note that the author did not fall into the error of attributing to a formula pronounced by Prof. Perry of greater importance than the author himself gave it, an error that is chargeable to others in the same field who can find a confirmation of the speculation in every set of investigations, whether contrary to the meaning of the equation or not.

Finally the paper is useful in bringing out certain defects in present methods of computation relating to overall efficiencies of boiler and furnace; gives a method of separating boiler performance from furnace performance; allows us to determine independent of the furnace, the best boiler arrangement; affords a means for determining the most economical or satisfactory capacity at which to operate the boiler of which characteristics has been prepared; gives some idea as to the relative proportions of furnaces to operate satisfactorily with a boiler which has its characteristics prepared; throws light upon how to determine the suitableness of different types of boilers or different units and shapes of the same type.

Mr. C. W. Naylor, M.W.S.E.: As I have not had an opportunity to read Mr. Stowe's paper, I am not in position to discuss it intelligently. I infer from the discussion and from the remarks of the speaker, and also the illustrations shown, that the author of the paper has simply exemplified the truth that there are a great many points of view from which we can look at boiler work and furnace work.

Mr. Arthur Frith: I am much interested in the tests which have been made by the United States Geological Survey, and they are of great value to the engineering profession. I would like to call attention to the fact, however, that the curves and diagrams shown are characteristic of only one particular boiler. Unfortunately a great many of the boiler tests made are on a particular boiler for a particular purpose, and the over-all efficiencies have been determined to obtain desired commercial results. Such tests represent a great deal of labor, but the very information which would be useful to those who are investigating this subject in a general way, are left out. For this reason, in many cases the information collected has not the value that it would have if the boiler upon which the test is made were described, and a cut included, showing the number of tubes, spacing, height of tubes, etc.

In this connection I want to refer to the tests made in Chicago several years ago, mentioned by Mr. Bement. In those tests complete data were given, with the result that certain matters could be determined later on, because the exact apparatus upon which the tests were made was described. Simply as a suggestion, I think that it would be a good thing if such information could be incorporated, not only in such papers as these, but in connection with ordinary commercial tests. This criticism applies to the code for Boiler Tests recommended by the American Society of Mechanical Engineers and that from such a test, as has been published, no conception can be had of the character of the boiler used. I should say that more than 90 per cent. of the boiler tests made are practically valueless for a certain class of investigation.

With regard to these particular diagrams, etc., I think that a good deal of the information that is somewhat obscure would be clearer, if we understood that the available heat is the difference between the temperature of the steam and the temperature of the gases. The available temperatures are given as the temperature of the furnace, but the available temperature is the *difference* between the temperature of the furnace and the temperature of the steam.

Mr. Ray: I wish simply to say, with reference to the criticism made by Mr. Frith, that the method outlined in the discussion submitted by me will be independent of the boiler water temperature in so far as we know now; it has proved so in a number of tests. In other words, the constant, true boiler efficiency nearly works out at the same temperature as the atmosphere. In fact, it is dependent solely on the mechanical shape and size of the boiler that comes from the shop.

Mr. Abbott: Your Chairman wishes to state that he recognizes that the U. S. Geological Survey is doing a work which will improve our boiler service and boiler construction, and will bring to the users of steam and to the designers of steam generating apparatus, a clearer knowledge and insight into some of the underlying principles which are now so confused, and so much disputed. In the

paper which has been presented this evening the Chairman recognizes a valuable contribution to the series of papers which has emanated from those who are or have been connected with the U. S. Geological Survey.

CLOSURE.

Mr. Stowe: In Mr. Abbott's riddle, the rate of combustion is to be a fixed one, which means that with a given stack the effectiveness of the draft facilities must not be altered by the selection of the boiler. The riddle can be made more comprehensive if put in this form: Having given several boilers, each of which under similar conditions offers the same amount of resistance to the flow of gas over their surfaces, which of these boilers is the most efficient as an absorber of heat? The answer is not to be found in the paper here presented, nor can it be expressed in a simple statement. I believe the correct solution can be obtained only by the judicious use of a chart similar to No. 6, where the design of the boilers can be used to account for their peculiar characteristics as heat absorbers.

Mr. Bement says that we know both by experience and reasoning that with high furnace temperatures, efficiencies secured by the boiler can not increase with the capacity developed. If I had arrived at the conclusion which his statement contradicts, through reasoning, I would not have set it forth in this paper for fear my reasoning would have been fallacious. It was only upon the experience gained by the studying of the 355 tests that the assertion, that at very high initial temperatures the boiler's efficiency increases with capacity, was made. We need not expect the efficiency to continue to increase with capacity beyond the limits that have been investigated. No doubt with higher capacities, say 100% of rating, the efficiency even at these high temperatures will fall rapidly. That the efficiency may increase with the rate of working, within certain limits, is not such a sensational statement as it might at first appear to be. Within certain limits the efficiency of electric motors and steam engines increases with the power developed and I see no reason why we may not expect the same conditions in steam boilers. There may be ways of accounting for the fact that efficiencies increase with the capacity at high initial temperatures other than by attributing it to the greater effectiveness of the increasing gas velocities at the higher temperatures, but this explanation will be offered as one having some merit until it has been proven otherwise or a more logical one substituted in its stead.

Mr. Bement suggests that at the higher capacities, water not detected by the calorimeter may have been carried away in the steam, thus making the boiler efficiency appear higher than actually existed. An inspection of Chart 3 will show that if this was the case and a correction were to be made for it, the right hand end of the lines of uniform boiler efficiency would be slightly raised, which would only cause that temperature at which the boiler efficiency remains a con-

stant for all capacities investigated to be increased from 3300 deg. F. to some higher temperature, and he would still have to account for the efficiencies increasing with the capacity.

In criticizing Chart 6, Mr. Bement states, as though it were a self evident fact, that "the variation between the efficiency of two different boilers is at a minimum with high initial temperatures, and at a maximum with low, but the highest efficiency is always obtained with the best boiler, initial temperatures being equal for each." To me, however, it seems very possible that two boilers of different design may, when run at the same capacity and with the same initial furnace temperature, have the same efficiency (Point E, Chart 6). Yet, I do not believe that it would be safe to reason that the coincidence would exist at higher or lower temperatures which means that the characteristic lines A-B and C-D would diverge as they leave Point E.

Relative to furnace efficiency, Mr. Bement states that a fire is made under a boiler for the purpose of heating its contents and that less heat passes to the boiler when the air supply is in excess than when the air supply is proportionately low, and because of the fact that the air supply is not taken account of, he objects to applying the term furnace efficiency to the amount of heat developed expressed in a per cent of the calorific value of the fuel. He does not give his definition of furnace efficiency, but it is apparent from his referring to the amount of heat that would pass to the boilers, that in his opinion, furnace efficiency should involve the idea of the effectiveness of the furnace and thus take into account the use to which the furnace is put. He could have criticized my definition of boiler efficiency E_b with exactly the same logic by saying that the purpose of a boiler is to furnish steam to an engine and as pressure is a factor in the economical use of steam, no definition of boiler efficiency can be correct which neglects pressure. One of the purposes of the paper is to be able to separate the furnace from the boiler and therefore I have given to the term furnace efficiency a meaning which can be applied independent of the requirements occasioned by the particular purpose of the furnace. When a furnace is used for such purposes as drying coal, burning building brick or baking enamel, minimum air supply resulting in destructive temperatures would not be desirable, and we could not, in these cases, think of a minimum air supply contributing to high furnace efficiencies. Therefore, as Mr. Bement's conception of furnace efficiency must take into account the use to which the furnace is put, it is not independent of the boiler's requirements.

Apparently his idea of a perfect furnace is one which develops all of the heat value of the coal and does so with only that amount of air which is necessary for complete oxidation. With this as an idea of 100% furnace efficiency, it is interesting to speculate on the probable significance of any other numerical value, such as a 50% efficiency. Would it be a furnace that developed all of the heat but

used twice as much air as when the efficiency was 100, or would it be a furnace that developed only half the heat value of the fuel, using the same amount of air as when the efficiency was 100, or would it be a furnace which caused the boiler to absorb only half as much heat per pound of coal as when the efficiency was 100? These questions are given to exemplify the truth of the last statement under the heading of furnace efficiency in the paper proper, viz.: That the idea of an efficient furnace, in the sense of its being effective, includes both quantity and intensity of heat and can not be expressed by a ratio.

I believe it would be out of place to discuss here the method of studying a boiler's performance that has been presented by Mr. Ray, which method if it is ever fully developed should form the subject matter of a separate paper. Further, his use of the terms radiation, conduction and convection convinces me that his conception of the meaning of these terms is different from mine, a fact which makes discussion impossible unless a reference to the meaning of these terms is made and something said about the way the phenomena of radiation, conduction and convection are manifest in a boiler performance. This does not appear in the paper I have offered because it is unnecessary in the method of study which I have presented, to consider by what means a boiler receives its heat. Inasmuch as this is not necessary, neglect to separate the amount of heat absorbed by the boiler, through the influence of radiation, from that absorbed through the agency of convection—a separation which Mr. Ray acknowledges himself, is impossible to even approximate—should not be considered a fundamental fault. I should say one fundamental fault lies in his method of study if he effects such a separation and neglects the influence of radiation. I may suggest another fault in his proposed method in addition to those he himself has given, and that is that the initial temperatures and boiler capacities dealt with would be so ridiculously low that the results would give no indication as to what would happen when the boiler was put in actual service. Mr. Ray says he knows of no accurate or easy method of determining "whether cross baffling a boiler of a parallel flow type causes it to absorb more or less heat from the gases at any or all rates of working." Apparently, he has not carefully read the paper presented, for the use of Chart 6 has been offered as an accurate method and while it is not an easy one, it is at least practical.

I wish to correct the statement made by Mr. Ray, as regards true boiler efficiency. The true boiler efficiency used by the U. S. G. S. and designated as E_4 is the same true boiler efficiency designated in this paper as E_1.*

Mr. Kuss mentions the fact that when the velocity of the gas over the heating surface is increased, more of the heating surface is brought into actual service because the path of the moving gas is

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*A study of 400 steaming tests U. S. G. S. Bulletin No. 325, p. 143 and figure 66 p. 144.

widened. This of course contributes to the maintaining of the efficiency when the capacity is increased. If, however, the efficiency were a function of the ratio of effective heating surface to gas used per unit of time, the heating surface passed over would have to be doubled in order for the efficiency to remain constant for both 70 and 140 per cent of rating. Obviously this is not the case, and an additional cause for the condition must be assigned. This additional cause, which is I believe the main one, is that the increased volicity tends to equalize by convection, the temperatures in planes of gas at right angle to the direction of flow, thus increasing the otherwise low temperature intimately adjacent to the surface of the tube, which increase allows the metal to absorb heat by convection at a higher rate.

A description of the boilers, furnaces and stacks used by the U. S. G. S. and the methods of conducting the tests is given in the first few pages of Part 2 of U. S. G. S. Professional Paper No. 48. The description was not given here, for it was the method of study I wished to call attention to, rather than the performance of a particular boiler.

THE DEVELOPMENT OF AN ALTERNATING CURRENT DISTRIBUTING SYSTEM

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The increasing use of electricity for lighting and power purposes in the outlying portions of the large cities and the extension of metropolitan systems to include suburban towns within a range of 25 to 30 miles imposes upon the distribution engineers of the larger systems problems which include all phases and varieties of distribution work.

This paper will include a discussion of some of the problems which are common to the development of every alternating distributing system as well as others which are encountered only in special cases.

The service supplied to an outlying or suburban district must necessarily be given through the medium of alternating current on account of its scattered nature. This involves three principal elements primary feeders and distributing mains, transformers, and secondary distributing mains.

Each transformer is essentially a small substation which receives electricity at approximately 2200 volts and delivers it at approximately 110 and 220 volts. The distribution of electricity from this minature substation must therefore conform to the laws governing the distribution of electricity at low voltage. This means a comparatively heavy cross section of copper and short runs.

The growth of a distributing system consists for the most part of a number of small and scattered increments of load which affect the secondary system and the transformer before they affect the primary system. We will therefore consider these questions in the reverse order from the flow of electricity, but in the logical order of reinforcement of the physical plant.

Secondary Distribution.

A system of secondary mains passes through three general stages of development in expanding from a small to a large system.

1. A period in which scattered transformers supply isolated secondary mains not interconnected with other transformers.

2. A period in which the mains from adjacent transformers grow together along principal thoroughfares where they may be connected to each other, but intersecting few other secondary mains of importance.

3. A final stage in which secondary mains are required on nearly all streets and are therefore joined into a net work.

The first period is that found in residence and other outlying territory not fully built up. When a new consumer is to be connected in such a territory the problem is: Shall a transformer be installed

or the nearest secondary main extended to the premises? The installation of a transformer involves an investment and an operating expense, due to its core loss. The extension of the secondary main also involves an investment in conductors and perhaps an increase in the capacity of an existing transformer. The cost of the two alternative plans being ascertained, the one selected should be that which involves the least annual cost for interest, depreciation and operation.

There is little occasion in this period of development to connect secondary mains in multiple. Where the mains have been extended until they meet each other it is usually preferable not to connect them, as the blowing of the fuse of either transformer shifts the load to the other and overloading it blows its fuse also; and transformers are so far apart that they cannot share each other's load to any appreciable extent in case of an overload on either of them.

The second period of development is reached when consumers become so closely situated that it is necessary to provide a secondary main along the entire length of a thoroughfare. This condition is usually first met along business streets and boulevards, and results in a long secondary main fed at intervals by transformers, but intersected by few other secondary mains of importance. When such a main has been established it is the problem of the engineer to determine how far apart transformers should be located and what size of conductor should be used.

The density of the load varies in different parts of the street and there are large blocks of load at particular points which make the problem a perplexing one at best.

Calculations made on the assumption of an evenly distributed load on a straight secondary main 10,000 feet long, with transformers and wire figured at average costs of the past few years indicate that where the load is heavy enough to derive any benefit from inter connection the most economical arrangement of transformers occurs on overhead lines with a spacing of about 500 feet apart when the drop on the secondary main averages 2 per cent. from the transformer to the most remote customer's service.

With underground lines the most economical spacing is between 300 and 400 feet.

The variation of annual cost for several load densities with three-wire Edison mains overhead, is shown in Fig. 1. This also includes a curve showing the cost of a four-wire three-phase secondary, carrying a load with a density of 150 kw. per 1,000 feet. It will be noted that the cost of three-phase four-wire secondary distribution is considerably greater than the cost of Edison three-wire distribution. This is due principally to the fact that 25 kw. transformers are required on a four-wire three-phase secondary as compared with 50 or 75 kw. units, with an Edison three-wire secondary. The smaller transformer units involve a greater investment and an increased core loss.

The three-phase four-wire secondary system is therefore an expensive system of secondary distribution as well as a difficult one to operate with a proper balance.

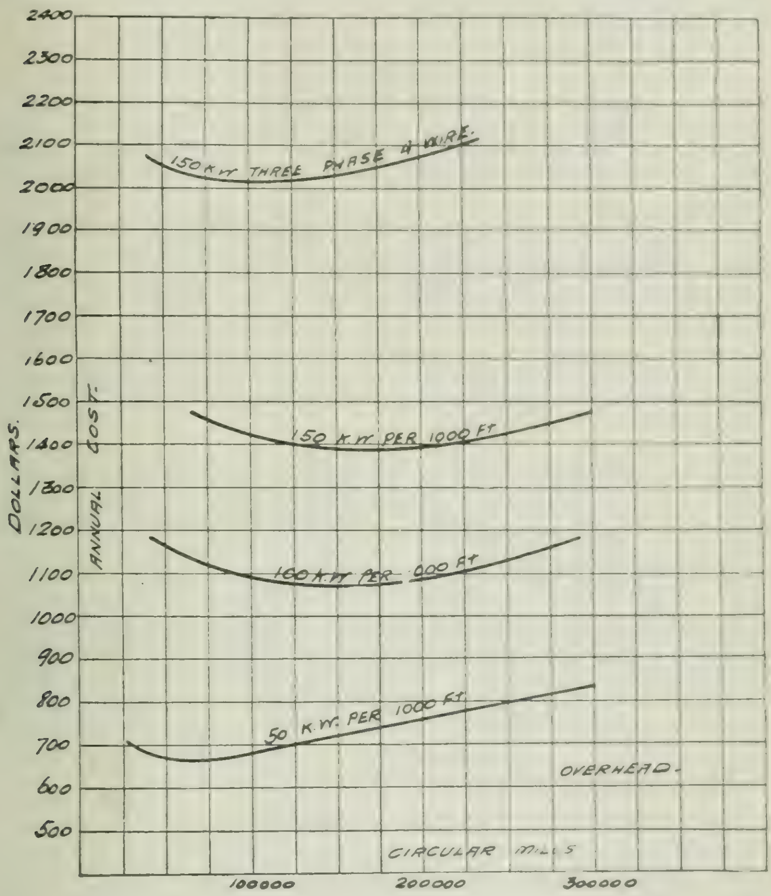

FIG. I.

The figures used in the curves are based on an assumption that the load is evenly distributed along the line throughout its length.

Unfortunately such is not the case in practice. It is usual to find a portion of a secondary main heavily loaded and other portions more lightly loaded, owing to the differences in the character of the neighborhoods through which it passes. At intervals a large store, church or other consumers of electricity may throw heavy loads upon the line.

It is therefore necessary in practice to locate transformers as closely as possible to such large consumers' premises and design the

main between them to carry the scattered consumers whose load is approximately evenly distributed. An extended secondary main may therefore be made up of several sizes of wire at different points with transformers having various spacings, depending upon the load density in the vicinity.

Networks.

The network is the last step in the development of a system of secondary mains. It consists of mains running at angles so that they cross each other and may be interconnected at intersecting points.

Transformers are located at points of intersection so that they deliver current in each direction with the best economy of copper. The transformers thus maintain the full feeder end pressure at all junction points where they are placed, as the primary mains are usually so short that there is no appreciable drop in them. This is an advantage over a direct current network where each feeder is connected to the network in only one or two places, and the mains must have greater capacity in order to maintain an even pressure throughout.

Large networks are usually underground since this form of construction is commonly required by municipalities in congested sections. This form of construction is favorable to the maintenance of lines and the requirements of continuous service.

The provision of manholes of suitable size for the large transformer units required in sections where the load is very dense becomes a difficult problem. The presence of conduits, gas pipes, water pipes, car tracks, etc., utilizes so much space that it becomes a physical impossibility to secure clear space in manholes for large transformers, except by excavating to a depth where drainage becomes impossible. The difficulty and expense under such conditions may make it preferable to establish a transformer substation from which low tension feeders emanate as in direct current systems.

Power Secondaries.

Where both power and lighting service must be given in the same locality, provision must usually be made for separate transformers and secondary mains for power service on account of the poor regulation of transformers carrying inductive loads which produces flickering and insufficient light when motors are connected to the same transformers with the lighting.

Secondary mains for power purposes may be designed with as much as 5% drop, however, and may therefore be extended somewhat farther from transformers than lighting secondaries.

In manufacturing districts the power load exceeds the lighting load, but is usually so much scattered that no secondary mains of great extent are developed.

In mercantile districts of medium sized cities where there is a fairly heavy load of both light and power to be served, it is often

a serious question to determine the best methods of giving light and power service with a minimum investment in conductors. Where the power load is less than 50% of the total and where the transformer capacity is so great that starting current of individual motors is not noticeable, it is permissible to combine lighting and power secondaries in one system. In a two-phase system this requires a three-wire secondary, carrying the lighting on one phase and two extra power wires for customers requiring both light and power, making a five-wire system. In a three-phase system two methods are available, each of which requires four wires. In the first the lighting is carried on one phase with a three-wire Edison secondary. Two smaller transformers are connected to the other two phases and a fourth wire brought from them, which, in conjunction with the two outer wires of the lighting system, give three-phase service. The fourth wire and transformers need only be of sufficient size to carry the power load.

In such a system, however, all the lighting transformers of the given feeders must be connected to the same phase if the load is dense enough to make the use of interconnected secondaries advantageous.

In the case of a very dense load carried on underground mains where the size of transformer units is as large as it is practicable to use, the four-wire three-phase secondary with transformer secondaries Y connected has certain advantages. With a network, the larger diversity factor tends to facilitate the work of maintaining a balance and to minimize the objections which apply to this system where it is used on smaller load densities. With underground lines any system which requires separate light and power secondaries involves the cost of one extra duct and extra conductors for all services which require both light and power.

Size of Transformers.

The selection of the proper size of transformer for the supply of various classes of consumers is a matter of great importance since excess capacity involves idle investment as well as unnecessary core losses. The size of transformer units should therefore be kept as low as possible consistent with heating of the apparatus and good regulation.

Very few electric light and power consumers use their entire connected load at any time. In lighting there are always some lamps which are not in use at times when the principal part of the lighting is on, and for power the load is frequently less than the rated capacity of the motor. Where there are a number of motors in use the maximum load is rarely on all of them at the same time.

Certain ratios of maximum demand to connected load may be established by a series of measurements for the various classes of consumers for which it is necessary to select transformers. These ratios may then be applied with reasonable certainty to the selection of transformers for new consumers.

For instance, it has been found in the City of Chicago that in store lighting the maximum demand for window lighting, signs and other display lighting is practically 100% of the connected load. The demand on interior store lighting is 75 to 80%. There are usually two or three nights in the week in which the demand will be less than this. In residences where the connected load is 50 lights or more, the average maximum demand of a group of residences is 15 to 20% of the connected load. Individual residences may have occasional maximums of 30 to 50% for which some allowance should be made in selecting transformer capacity. The size of the transformer should be such that it will carry the occasional high maximum of the largest individual consumer together with the average maximum of the other consumers on the transformer. Oil transformers may safely be permitted to carry 25 to 50% overload occasionally in such cases.

Small residences and apartments having connected loads of 40 lights or under average about 20% of the connected load, with 25 to 30% as an occasional maximum.

In general, a higher ratio must be used where there are but two or three customers on a transformer than where there are ten or more consumers, as the occasional maximum of individual consumers is a much larger percentage of the total.

In the case of churches and similar public buildings capacity must be provided for the illumination of the largest room in the building together with the necessary hallways and corridors. This usually requires capacity for at least 75% of the connected load.

In theatre lighting, allowance may be made for the use of border and foot lights of several colors which are not used simultaneously and for the fact that the stage and auditorium are not lighted simultaneously except for a very few minutes at a time. In a small theatre the ratio may be from 70 to 85% while in a large theatre it frequently runs as low as 50%.

Where several classes of buildings are fed by one transformer, the capacity must, of course, be determined by taking each class into consideration separately and thus arriving at an average ratio for the whole.

The selection of transformers for power consumers is a more difficult task, as the maximum load may vary greatly from day to day or from month to month. Consumers having but one of two motors generally require from 60 to 90% of the aggregate horsepower of their machines. The connected load should be estimated where possible from the nature of the work done rather than from the motor ratings, as motors are frequently chosen with reserve capacity. Where there is a considerable number of motors the maximum load is often not more than 40 to 50% of the aggregate rated horse-power of the motors. Elevator and crane motors require transformers of 100 to 125% of their rated capacity unless there are several motors supplied by one unit. This is necessary in order to hold up the pressure in starting. The load of such equipments is so in-

termittent that heating is usually not a factor in determining the size of the transformer.

The type of transformer which has proven most adaptable to conditions of outdoor service is the oil cooled core type with a weather proof case.

It is customary to provide two sets of coils on primary and secondary so as to make the transformer interchangeable for 1000 or 2000 volt systems and to permit their use on either 110 or 220 volt secondaries or three-wire Edison secondaries. The core type has proven to be the easiest to insulate to a high degree and has external dimensions which are well adapted to location on poles or in manholes.

The improvements in recent years have resulted in the reduction of iron losses to a minimum, but there is some doubt as to whether the recent tendency to make a saving in the weight of copper required by increasing the leakage of current is one which should be encouraged. A design which requires a leakage current of 5% of the normal full load current of the transformer at a power factor of about 30% if carried out through a large system would require the operation of extra generating capacity during the light load period to supply the leakage current.

Primary Mains.

The development of the primary distributing system is carried on chiefly through short extensions made from time to time for the purpose of reaching new customers which are secured in locations where no lines have yet reached. For the most part these are one or two blocks long and the load added usually does not amount to more than a few kilowatts in the case of lighting and from 5 to 150 horsepower or more in the case of power. In case large power customers are added, it is sometimes necessary to reinforce the primary system by extending the feeder to a point nearer where the heavy load is to be carried. In general, however, the large reinforcements of the primary system are provided in connection with an annual readjustment of the arrangement of feeders, which is commonly installed during the summer months so that it may be ready for service in time for the heavy load period of the fall and winter.

Feeders.

It is usual to adopt a standard feeder equipment having a maximum load rating of from 150 to 200 kws. per phase. Station equipment and line copper are provided with this ultimate maximum load in view. As soon as the load on the feeder has reached this maximum, it is necessary to provide additional feeders for the relief of the overloaded feeders. These feeders must be run to points in the primary main system where they may be connected in, to pick up portions of the load of other feeders.

This work sometimes requires considerable study to arrive at the best points, for new centers of distribution, as the routes of primary

mains are usually fixed by the location of streets and alleys and frequently cannot be arranged to make the most desirable electrical lay out. Primary mains are usually operated according to a plan similar to that shown in Fig. 2. It will be noted that each branch has but one source of supply and that no system of interconnection is carried out. The distance covered and voltage employed are such that very little advantage is gained in regulation from interconnection whereas from an operating standpoint there are serious disadvantages.

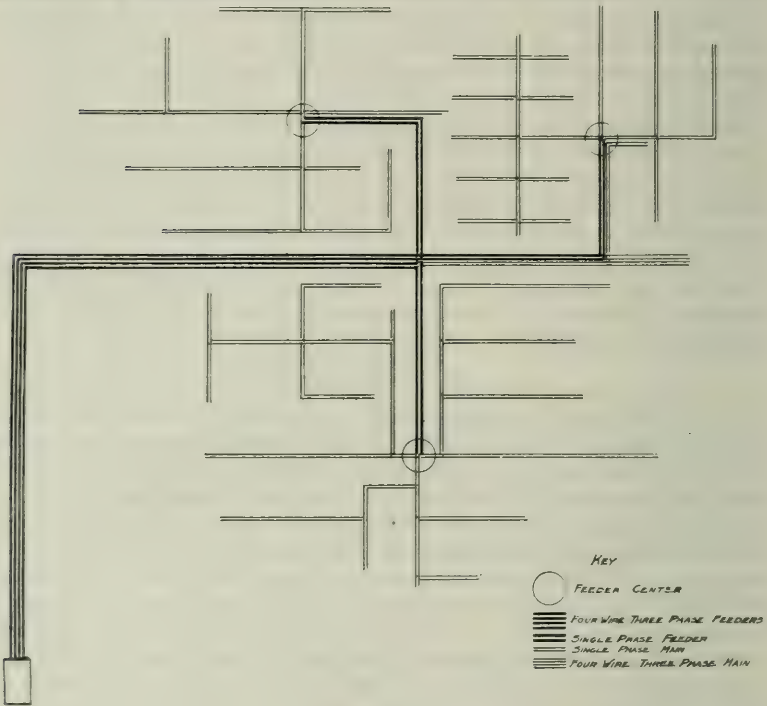

FIG. 2.

Systems of Distribution.

Primary distribution is carried out on various plans in different cities, the selection of the system being governed by many local conditions such as the relative amount of light and power, nature of construction (whether underground or overhead), amount of equipment which would be rendered obsolete in case of a change, etc.

One may find in the smaller American cities, primary distribution carried out on the single phase system at 1,100 or 2,200 volts at 60 or 125 cycles. One hundred and twenty-five cycles and 1,100 volts are, however, now practically obsolete. The single phase system is used mostly in small towns where no power consumers requiring more than 25 to 40 horse-power each are supplied and where the power load is small.

Two Phase.

Other cities, such as Philadelphia and Brooklyn, are employing two-phase three-wire distribution. Single phase branches are taken from the two-phase feeders where lighting only is required. The voltage from either phase wire to the common wire is approximately 2,200 while that between phase wires is approximately 3,000. The neutral wire in this system carries 41% more current than the phase wires and where feeders are run at their rated capacity, the neutral must be 41% larger if equal heating of conductors is to be secured. This, however, is not usually necessary on the primary distributing mains as No. 6 wire is used in any event for mechanical strength and for the majority of the system it is ample to carry the neutral current.

The amount of copper required on the feeders of such a system where the neutral is made 41% larger than the phase wires is about 15% less than the single-phase system. For the same energy loss, however, the copper required is the same for both systems. The only advantage which the two-phase system has over the single phase system, therefore, is the ability to supply polyphase motors for large power distribution.

Four-wire two-phase distribution in which the two phases are kept separate is used to some extent, but has not been generally adopted owing to the extra expense of a fourth wire carried throughout the distributing system without any advantages to offset it.

Where two-phase systems are employed for distribution it is usual to transform to three-phase for transmission on a wholesale basis.

Three-Phase Three-Wire.

The three-phase system is perhaps the most generally employed method of primary distribution. This is accomplished by two methods, commonly known as the three-wire and the four-wire.

In the three-wire three-phase system the voltage between phase wires is approximately 2,200 and transformers are connected from phase to phase. Lighting lines are operated from one phase of the three-wire line. Where three-phase power is to be delivered, which is usually for installations of 5 horse-power or larger, three-wires must be carried and either two or three transformers installed. Two transformers with secondaries connected on the open delta plan are usually found satisfactory for power consumers whose requirements do not exceed 25 H.P. The advantage of this method is reduced cost of transformers, iron losses and expense of installation. The unbalance caused by such consumers is not serious as it may be readily offset by single-phase taps connected to the other phase.

In sections of cities where the load is principally lighting, but where three-phase power is required for occasional elevators and similar equipment, it is usual to connect all the lighting to one phase, two of the wires being made of proper size for this purpose. A third wire of No. 6 or No. 4 is carried into the district to supply such small power business as it may be necessary to serve.

This plan has the advantage that a regulator may be installed in one-phase wire and accurate regulation provided on the lighting phase. Where lighting is carried on all phases it is necessary to install regulators in each phase wire with the result that the operation of either regulator affects the pressure on the two phases and renders the work of pressure regulation too cumbersome.

For a large system where the number of feeders must be kept down to a minimum and where they must be loaded to the best advantage, this system, therefore, has serious limitations.

Four-Wire Three-Phase.

For such situations the four-wire three-phase system has decided advantages over the three-wire system and has, therefore, been adopted in several of the larger cities, notably Chicago and Cincinnati.

The special advantage of this system is that where there is sufficient load to require a three-phase feeder, the transmission is effected at 3,800 volts, and loads up to 500 kw. may be distributed from a single feeder at distances of over three miles from the station with four wires, whose size is fixed only by their current carrying capacity.

The neutral wire in this system naturally runs near earth potential and is, therefore, usually grounded at the generating station. This makes it necessary to look somewhat more carefully after the insulation of lighting arresters, cables at points where they join overhead wires, fuse boxes and other fittings, than in other systems. It is also necessary that linemen exercise more care in working on lines where there are two or more phases present, since the difference of potential between phases is about 3,800 volts instead of 2,200. This system requires one-third the copper in feeders required for a single or two-phase system at 2,200 volts, or 44.4% of that required for a three-wire three-phase system at 2,200 volts under equivalent conditions.

Standard 2,200 volt transformers may be used for all purposes, being Y connected for power purposes and fed from a phase wire and neutral for lighting purposes.

The feeder lay out shown in Fig. 2 is a typical one for a feeder supplying a residence district where the three-phase mains do not cover the entire territory.

In a section where there is mercantile lighting and manufacturing business the four-wire mains usually cover the principal thoroughfares in the section supplied by the feeder. This system also possesses certain advantages for transmission purposes where suburban sections are to be supplied and where the extent of the load does not warrant the erection of an expensive substation. In such cases the erection of a four-wire line operated at double or triple the main distributing voltage, will double or triple the radius of supply and thus enable the load to be delivered at the remoter sections with no more than normal feeder line loss. The step-down transformers may be of the weather-proof type mounted on a suitable platform in the

open and thus require no attendance or substation expense other than the investment in the transformer.

In this manner a four-wire line may be used to carry several adjacent suburbs at minimum expense and yet give the suburbs as high class service as is given by the feeders operated direct from the main station. This is possible because of the use of the fourth wire which takes care of the unbalanced load and which in conjunction with line drop compensators and feeder regulators on each phase makes the matter of unbalanced load one of no consequence.

In cities of such size that the length of feeders and load distributed, results in the extension of certain feeders beyond the radius of economic distribution, the usual procedure is the establishment of substations. These receive energy at a potential of 6,600 to 13,200 volts by means of duplicate transmission lines and convert it to the distributing voltage. In some of the larger cities, such as Chicago and Brooklyn, where the energy is generated at 25 cycles, the substation must be a motor generator frequency changing station. Otherwise, the substation consists of transformers, switching equipment, regulators and the like.

The establishment of a substation becomes advisable when the investment in feeders to a given area from existing sources of supply seems likely to equal the cost of a substation and transmission lines. In a growing system the location of substations may be made in advance of the time when they are an economic necessity, in order to avoid the abandonment of feeder equipment.

This is more particularly the case with underground lines. The transmission lines should be well protected at stations, should follow different routes as far as possible and should be of such capacity that the loss of a line will not put any part of the substation load out of service, more than a few minutes, in case of trouble.

Construction Methods.

The evolution of an alternating current distributing system is materially affected in many cases by the class of construction which is permissible. In territory where overhead construction is allowed by the terms of the franchise, small customers can be taken care of by making comparatively inexpensive line extensions which would be prohibitive in the underground territory. On the other hand, growth in underground territory must often be based on future prospects rather than on the immediate returns to be secured. Likewise the electrical layout where overhead construction is adhered to, may at times look very inconsistent when laid down on paper in diagrammatic form on account of the restrictions placed on overhead routes.

It will not be possible in the scope of this paper to discuss all of the points affecting the construction of a distributing system, but we may consider briefly some of those features which are of more particular interest.

Overhead Work.

The design of the pole line in distribution work differs from transmission line work in that the direction of lines changes frequently and that corner poles must often be self sustained as guying is impracticable. This necessitates the use of reinforcement around the base of the pole by means of planks or concrete. The planking method is preferable where the digging is easy while concrete is usually used where the size of the hole must be kept down to a minimum. Six or eight inches of concrete placed around the pole on one side is usually sufficient to give the necessary increased bearing surface to prevent the pole from pulling over. Strains on corner poles which are self-sustained are relieved in part by the use of head guys to the next pole in each direction. Similar construction is sometimes necessary in the case of cable poles where overhead lines are dead ended and connected to underground cables.

The spacing of poles is affected by the length of blocks, width of lots, arrangement of alleys and the number of services which are to be taken off. Span lengths may therefore vary from 75 to 125 feet or more.

It is important that poles be placed opposite lot lines to minimize interference with the rights of abutting property owners and where spans are long it is difficult to reach buildings half way between poles with service drops. Where there are several more service drops going off one side of the pole than the other, it is sometimes necessary to use a pole of eight or nine inch top diameter to prevent the line being pulled out of shape. It is also desirable to use poles with heavy top diameter for large transformers; for self sustained corner poles and cable poles, 10 and 12 inch tops being used in some cases.

Where distribution is made by alley lines, the roadway is so narrow that poles must be set close to the property line which necessitates the use of side arms, commonly known as alley arms. The tendency to pull the pole over due to unbalanced strain is offset by giving the pole a slight rake toward the property line before it is set. Where the weight of the wires is considerable, as on main feeder runs, and where wires are dead ended, it is necessary to put on a double set of cross arms to support the strain.

Where transformers of 20 kw. and larger are to be supported on poles, it is desirable to use an extra heavy cross arm in order to provide an ample factor of safety. Single transformers up to 50 kw. and three-phase installations consisting of three 30 kw. transformers can be safely carried on a single pole with 4 by 5 in. cross arms, double armed. Where large power customers are to be carried involving three or six units larger than 30 kw. it is preferable to set extra poles and build a platform between them, as shown in Fig. 3.

In a number of the larger cities, and especially where alley lines are used, it is customary for electric lighting and telephone companies to maintain lines jointly. A clearance of five feet is maintained between the lower cross arm of the lighting company, whose

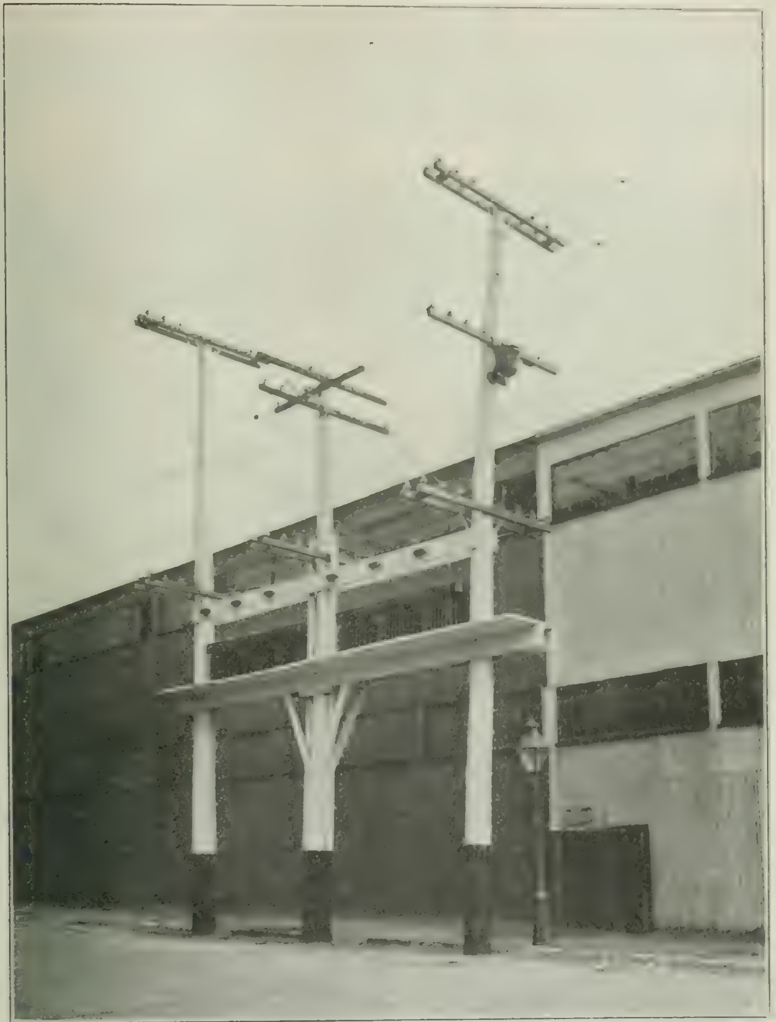

FIG. 3

wires are always carried on the top of the pole and the upper cross arm of the telephone company. Poles must, of course, be selected of sufficient height to provide clearance over buildings and obstacles in the thoroughfare and a sufficient working space for the equipment of both companies.

This class of construction has been found safer than separate lines on the opposite sides of the thoroughfare and the numbers of accidents which have resulted from the presence of primary wires on

the same poles with telephone wires has been less than those due to telephone service drops becoming crossed with electric light wires where separate lines are maintained. Fig. 4 illustrates a typical situation in Chicago, where this class of construction has been extended to practically all distributing lines.

Fig. 4

Underground Lines.

Where underground construction is required some form of draw in system has been adopted almost universally in American practice. Short extensions of secondary line have been made in some cases with Edison tube. Engineers have also in some cases laid steel

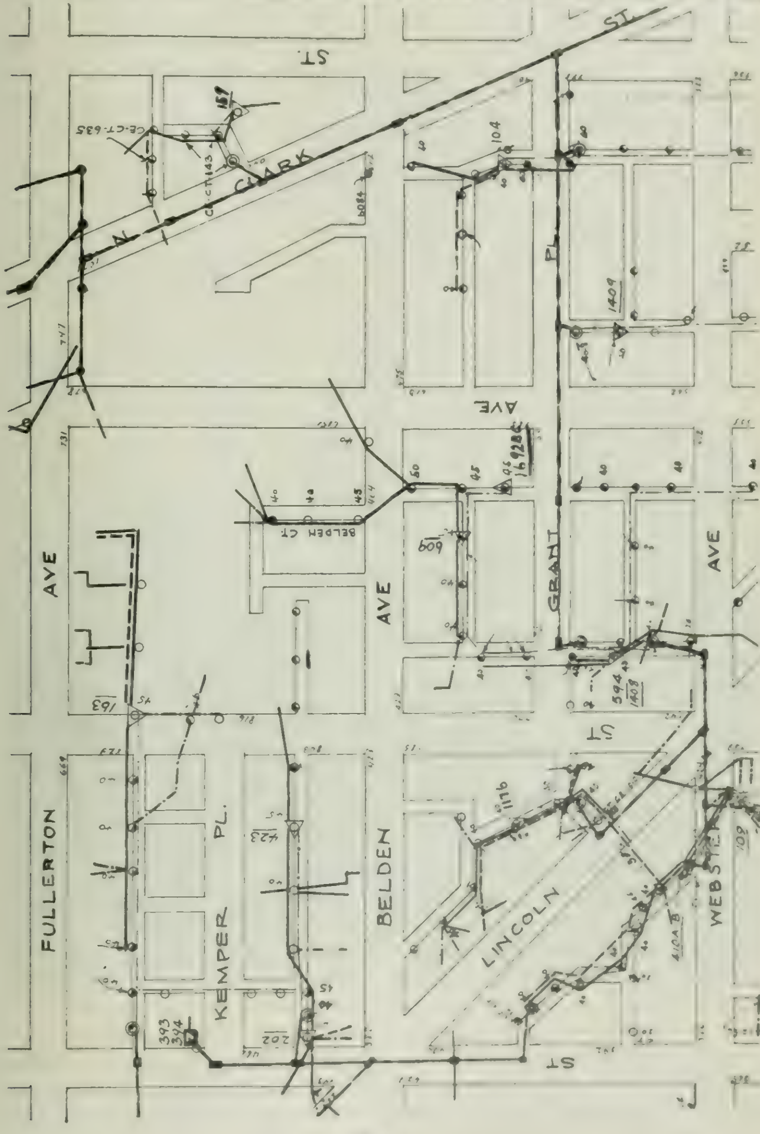

Fig. 5.

armored lead sheathed rubber insulated cable underground without protection other than perhaps a piece of plank laid above the cable. This construction, however, is limited to country districts where excavations are made infrequently and where the cost must be kept down to a minimum. The use of single and multiple conductor cables insulated with paper, varnished cambric or rubber and sheathed with lead to exclude moisture, drawn into tile duct, has become the standard form for installing circuits under ground in all cases where the importance of the service and the extent of the business will justify the investment. Multiple conductor cables are used only for through lines on account of the difficulty of making taps.

The use of single-conductor cable for distribution lines is somewhat more expensive in first cost, but is much preferable in operation. Along main business streets where the load is quite dense, it is necessary to install transformers in manholes and maintain a low tension secondary system from which cable services are taken into the buildings.

Transformers for this class of service must be provided with special water proof cases and the manholes in which they are placed should preferably be provided with sewer connection for drainage.

In the City of Chicago it happens that practically all the sections where the load is sufficiently dense to require such construction, are in direct current territory, and the use of subway transformers is therefore very limited. A considerable portion, however, of the primary distributing system has been placed underground. This has been accomplished by the installation of conduit lines on the main thoroughfares in which the feeders are placed, thus eliminating a considerable portion of the overhead feeder routes. This system has been further extended to include the principal branch lines which follow the main thoroughfares. The smaller taps taken from the main distributing lines are brought up the pole at the alley intersection and the transformers with secondary distribution are maintained overhead in the alleys. A portion of such a circuit is shown in Fig. 5. This method permits the removal of pole lines from all principal streets and avoids the expense of installing numerous manholes and service laterals which otherwise are required in connection with distribution by underground secondary lines.

A special form of detachable porcelain pot-head has been devised for making connection between the underground taps and the overhead lines, by which any overhead tap may be disconnected in case of trouble or for construction purposes, as in Fig. 6.

In the operation of the primary system it is desirable to reduce the number of fuses to a minimum, consistent with proper protection of small taps without interrupting service in too large an area. It is usually preferable to depend upon station circuit breakers to protect the station from short circuits which may occur on the feeder or any of the principal mains. The use of fuses on the principal mains is not practicable because of the large capacity which is required

and because thus far no fuse block has been developed which has proven thoroughly reliable when used with fuses of 25 amperes or upwards at 2,000 volts. It is important, however, that disconnecting points be provided at the feeder ends so that any main can be opened to facilitate the location of trouble.

Fig. 6.

The requirements of continuity of service demand facilities for interconnecting the mains of adjacent circuits in times of emergency. It is therefore important that the mains of each feeder be provided with means of interconnecting to other feeders so that in case of

serious trouble on any adjacent feeder, the mains of that feeder may be made alive, promptly. This provision is also a necessity where any construction work is to be done on a feeder which necessitates its being shut down during the light load period.

The adaptation of these principles to underground primary distributing systems is very important, as the occurrence of trouble on cables, while infrequent, is apt to result in much longer interruption of service and means must therefore be at hand by which the portion affected may be isolated, and the remainder gotten into service again very promptly. The range of subjects covered in this paper has precluded detailed treatment, but it is hoped that the points suggested will at least provoke discussion if they do not instruct.

Discussion

Mr. G. H. Lukes, M.W.S.E.: Mr. Gear has touched upon nearly all the problems that bother the distribution engineer. There are one or two points brought out that I would like to emphasize. He refers to the increase of leakage current in transformers of recent design. This may be a matter of considerable importance to companies supplying a lighting load in scattered districts in which there are necessarily a large number of small transformers. I hope that we may hear something from the transformer people about this.

In Chicago we are firm believers in the four-wire, three-phase system for primary distribution. The advantages of this system are clearly shown in the distribution in the district south of 71st St., Chicago. This section of the city includes an area of perhaps 150 sq. mi., in which there is a load of about 900 kw. It is supplied from 2 four-wire feeders extending from the 56th St. Station to two small sub stations at Fernwood and South Chicago. The voltage on these feeders is stepped up at 56th St. from 2300-4000 to 4600-8000 volts and stepped down again at the sub stations. The feeder regulators, however, are at the 56th St. Station and no attendance is required at the sub stations. It will thus be seen that a large area is supplied with a comparatively low investment per kw. and with a small distribution operating cost per kw. hr.

I have found that the most annoying distribution problems are encountered in cases where not only commercial but street lighting service is supplied from overhead lines. An overhead street lighting system, particularly if it consists of series incandescent lamps, requires poles on the streets. An alley system of distribution for commercial service seems, therefore, to result in a duplication of pole lines. Under such circumstances it is sometimes difficult to decide just which to do.

Mr. Roper, Chairman: I was interested in Mr. Lukes' remarks with reference to the satisfactory system of lighting in Chicago, and which he feels is the *only* system. I have heard exactly the same opinion expressed by engineers where they had quite a different system!

Mr. Hayward Cochrane, M.W.S.E.: I would inquire why it is easier to regulate in the four-wire, three-phase system, than in the three-wire, three-phase?

Mr. Gear: The difficulty arises from the fact that in the three-wire, three-phase system ,the regulators must be inserted in one of the wires and pressure must be taken across to one of the other wires, and the current going through one of those wires is not in phase with the pressure which is added to it, therefore, in regulating a three-phase, three-wire system, the operator must keep working these three regulations a good share of the time. On the four-wire system, the current is in phase with the pressure and the operation of the regulator effects only one phase, since the load is connected from phase wire to neutral, while in the delta system the load is connected between phases.

Mr. J. R. Cravath, M.W.S.E.: Mr. Gear has touched upon the question of tying together secondary mains. There are a number of smaller cities where it is the practice to tie their secondary mains together solidly, with a transformer every few hundred feet feeding into them. That is an arrangement which may operate satisfactorily for a year or two, or three years, without giving trouble, but sooner or later there is likely to be serious trouble. If one transformer gets a little overloaded and its primary fuses blow, its neighboring transformer will be immediately overloaded and its fuses will blow. This will continue from transformer to transformer, and it is only a few seconds until the whole line is out of service, and cannot be put back until each individual primary fuse has been replaced. I know of one case where that happened with disastrous results, and there have probably been a good many other cases.

Mr. Roper: There is one point that was not touched on in the paper, and that is the determination of the point at which it becomes advisable, from economical reasons, to go from overhead to underground distribution, on account of density of the load. That is a point that will arise at some stage in the development of every system, and it is one that is very largely influenced by ordinances, etc.

Mr. P. Junkersfeld, M.W.S.E.: The class of engineering described in this paper is not of the spectacular kind. It is, however, of the kind that is essential to enable a company to give good service to its customers and pay reasonable dividends to its stockholders.

A system such as Mr. Gear describes, was first installed in Chicago some eight or nine years ago—a four-wire three-phase system. In the meantime, the distribution losses have been reduced from about 50 to 30%. If you stop to think what that means, you will realize it is a great big matter in the operation of a company. This class of work, too, is one that requires a large amount of application. Matters may come up several times a day and if decisions are not made consistently, the best results cannot be obtained.

Several years ago among many people, the statement was made, especially in the larger cities, that the only system paying dividends were the ones operating with direct current. That is no longer true. We are approaching the point where, with well designed and carefully operated systems, by the use of alternating current a very good service can be given. Four-wire, three-phase networks are now being installed in some of the smaller cities, under conditions which I think are quite promising. In the denser part of this city, there is a direct current system and the alternating current is supplied only in the outlying districts where service is not quite so severe. It is rather unfortunate that the single-phase, three-wire system did not have a better trial, but that, too, has its limitations. It was tried in one place but has been discontinued, although it was really from no fault of the system. The trial was in a city and under condition where it did not meet the commercial demands of taking on isolated plants quickly, and in a city which was really too large for that kind of a system.

There is another thing that was not touched on much in the paper, in regard to underground construction. It is rather an old subject and has been referred to many times. There is a great demand for a cheaper form of underground construction, and there are a number of places in this country and in Europe where an armored cable system of underground construction answers very well, and I think the time will come in this country when, under certain conditions, that will have a wider application than it receives today.

Mr. Gear: There is one point which I did not discuss fully, but it has a very important bearing on the investment required to install these different systems. We have all read frequently comparisons of the amount of copper required for single-phase, three-phase, etc., systems, and the comparison is apt to be misleading on the face of it. If the single-phase system was generally adaptable to power work, it would be the best system of distribution which could possibly be used; better than direct current—better than any alternating current system—for the reason that what extra money has been put in feeders would be saved in the money that would be saved in having only two conductors instead of three or four on the distributing mains. The larger part of the investment in alternating systems is in distributing mains, not in feeders, and for that reason the single-phase system has a great many things to commend it, particularly where an underground cable is employed.

The matter of street lighting, as Mr. Lukes suggests, is one which should have received more attention than has been given to it in the paper. The street lighting in Chicago is almost entirely municipal, and what we have is carried on other lines of poles which do not involve any extra investment, but where street lighting is involved with another distributing commercial system, it makes a very perplexing problem.

SPECIFICATIONS AND NOTES ON MACADAM ROAD CONSTRUCTION

A. N. Johnson, M.W.S.E.

Presented Wednesday, Oct. 21, 1908.

The growing importance and necessity of improved highways in nearly all sections of our country, together with the fact that broken stone roads offer, in a majority of instances, one of the most practical and at the same time economic methods of construction, is sufficient explanation and excuse for the presentation of this paper.

In confining the subject to macadam construction the writer does not mean to have it inferred that he regards macadam construction as the only one for improved highways or that it is the method that is to be advocated for all roads in all communities. But it will be assumed that macadam construction has been decided upon, and our problem is to be discussed under this assumption, so that no discussion of the relative value, under various conditions, of macadam and other forms of pavement will be attempted. It was the writer's intention, and the paper was first prepared to present complete specifications for road work where macadam construction would be employed, including a form of contract, specifications for pipe and masonry culverts and the general causes that are common to specifications for public work. After reconsidering the matter, it was decided to omit everything except those sections that pertain to the construction of the macadam surface proper, leaving out all general clauses and notes thereon and also all specifications for pipe culverts and incidental work, which greatly reduced the length of the paper, which was becoming somewhat unwieldy. At the same time there is retained the most interesting portion, or at least that portion in which any change is suggested from the methods usually followed.

As will be noticed, the concise wording of the specification proper is first given, followed by notes in explanation of the purpose of the specification, the idea being that with the purpose of the specification explained it could be readily adapted to any given condition.

The writer appreciates fully the difficulty of preparing any general specification that would be of real service in specific instances. Such a difficulty exists no less in specifications for macadam road work than in any other line of engineering. But with the arrangement here given it will be possible to render a specification as outlined, adjustable for use under somewhat varying conditions.

It is not out of place to say a word in general regarding specification. There is often a great temptation to draw a too rigid specification. In this connection, Dr. Charles B. Dudley in his address before the American Society for Testing Materials in 1903, well expresses the penalty one pays for an over strict specification, as folows:

"Excessively severe limitations in a specification are suicidal. "They lead to constant demands for concessions, which must be "made if work is to be kept going, or to more or less successful ef- "forts at evasion. Better a few moderate requirements rigidly en- "forced than a mass of excessive limitations which are difficult of "enforcement, and which lead to constant friction and sometimes to "deception."

On the other hand, specifications should not be too lax and leave too much to the "opinion of the engineer." It is generally conceded that a good rule for specifications is to tell only what is wanted, and no more, leaving the method of arriving at the result to the discretion of the contractor. This is undoubtedly a good rule but does not cover all contingencies. Actual experience in road building, for example, has shown the wisdom of prescribing in certain parts of the work the method that shall be followed rathen than the result. This arises from the fact that while it is a comparatively easy matter to specify precisely what we want, which would be, let us say, a road with a smooth surface, properly graded, comfortable to travel, and which should show no sign of depressions or other inequalities under traffic at any time of the year, yet it is impossible to say from its appearance after the road is built whether it will fulfill our specification or not, except as time may develop the good or bad qualities of the work. We might, of course, require that the road show no signs of failure for a stated period, assuming that if it withstood the action of traffic and weather conditions for two or three years that it would be fair to assume it would withstand them successfully from that time on.

Such a plan, however, would withhold from the contractor such an amount of money as would be a very considerable inconvenience and expense even if this method could be justified on other grounds. But this procedure is not necessary. Experience has shown that if certain methods of construction are followed we are reasonably assured as to the results. It has, therefore, been found a better practice to limit the contractor as to the methods he shall employ, and release him from obligation as to the results. This latter condition is not aways considered, and one sometimes finds specifications which provide not only as to the exact methods the contractor must follow, but at the same time put an obligation upon him if a failure of any part of the work ensues. Such specifications are evidently unskillfully drawn as they can seldom be enforced at law, and are more or less evidence of the engineer's distrust of his own design and specifications.

Before we pass to the detailed consideration of our subject, a word should be said regarding the influence of modern traffic conditions on the methods of road building. In situations where but a few years ago there would be no doubt as to the efficiency and advisability of ordinary macadam construction, there is today much uncertainty in the minds of most highway engineers as to what is best. This change

has been brought about by the increase in motor vehicle traffic, and has attracted the world-wide attention and study of road builders.

There does not seem to be any question but that it is impossible to maintain in good condition an ordinary macadam road subjected to any large amount of motor traffic. It is only by applying some tough, elastic binder in the top or wearing course of the road that a macadam surface can successfully resist this traffic. The present practice is generally to use for this purpose either a coal tar or an asphalt compound. Sufficient experience, however, has not been had to determine definitely what will prove best. Although considerable knowledge has been gained in the methods of application, the test of time is yet to prove the relative worth of different methods and material. The problem for solution is, can macadam roads that will prove satisfactory and economical under the new traffic conditions be built with only a slight increase in cost? If it is necessary for the preservation of macadam construction to double or treble its cost, we have other kinds of pavement available which are known to be more durable and, if economy is the chief consideration, to be more desirable. But we enter here on the discusion of what kind of a pavement should be used, which, as before stated, is not to be a part of this paper.

There are, however, many miles of road that can be maintained as macadam roads. It also seems probable that where there is but a moderate amount of motor traffic such roads can be maintained by a comparatively inexpensive treatment which will insure a durable road surface at an expense not incommensurate with the worth of the road to the public. But we should keep in mind that even though our road today has but little or no motor traffic, it probably will have more, rather than less, so that our method of construction, wherever we can do so economically, should be changed to meet such a condition. The specifications and suggestions made here have been drawn with this idea in view.

SPECIFICATIONS.

ROAD-BED.

The road bed will be considered as that portion of the road upon which broken stone is to be placed. The road bed is to consist of the natural earth which has been brought to the proper elevation and cross sections and rolled by a steam roller until firm and hard.

If sandy or other soil be encountered which will not compact readily under the roller, a small amount of clay or other means shall be used until a firm, hard surface is obtained after rolling.

NOTE. The width of broken stone to accommodate the traffic ordinarily found on roads in agricultural sections of the country does not need to be over 12 feet. Here the traffic consists of wagons following one another, so that even where a greater width has been provided it has been found that the travel is confined to a single track so that the extra width has been built to no practical purpose.

It is often contended that 12 feet is not sufficient room for wagons to pass. This is true for some kinds of wagons. It is, however, usually a fact that the loaded wagons are all moving in the same direction at a given time in the day, so that the chances are that at least one of the wagons meeting will be unloaded and could turn out with little inconvenience, even in the worst weather. Inasmuch as this will happen but occasionally, the side of the road or shoulders will not be cut up. Serious inconvenience is experienced, however, in the immediate neighborhood of a town where residences may be or are in immediate prospect of being built alongside the road, which will occasion much repassing of light vehicles. If a sufficient width of macadam is to be provided where passing is frequent, not less than 18 feet is required.

Where the traffic consists of much pleasure driving, a width of not less than 16 feet should be made. Roadways that accommodate an amount of motor traffic, that necessitates frequent passing, should be not less than 18 feet; in fact, it would seem that due regard for safety would make the minimum width 24 feet.

With the large mileage of unimproved roads, and the small amount of money available for their improvement in most communities, it is important at first to build as great a mileage as possible; to which end the narrowest road practicable should be built. But not less than 12 feet is to be advised, for, if the traffic can be so directed, this is sufficient space for it to spread so as not to bring all the wear in one track. Roads 8 feet wide have been built and found a failure because of the fact that the traffic was confined to one track, so that the road actually wore faster and became more expensive to maintain than a wider road where the traffic had room enough to spread about and not bring all the wear in a particular place.

On the construction of the roadbed hinges the success of the road covering. The roadbed must be firm and shaped true to the cross section. Uneven places in the roadbed invariably appear in the surface of the finished road. When there is evidence of underground water, as shown by seepy or quaky places, there is but one remedy, and that is to remove the water by tile under drainage. Unless this is done the macadam is sure to cut through as the frost comes out of the ground. The most treacherous places will usually be found on the hillsides, and careful inspection should be made of all such places for signs of underground water. The fact that a road surface becomes deep with mud in wet weather does not necessarily show that under drainage is needed. In fact, on most of the level prairie roads it is not needed, but it is sometimes the most efficient way to take care of troublesome surface water. The essential thing to accomplish under such circumstances is to place the roadbed at a sufficient elevation to raise it above the surface water that may stand in the ditches at the roadside.

THICKNESS OF MACADAM.

The thickness of macadam to be used at any particular point shall be that as shown on the plans or as indicated in writing by the engineer. In general, there shall be three classes of macadam, known as 6-inch, 8-inch, and 10-inch construction. The thickness in each instance is to be that of the road after thoroughly compacting by rolling and completed in accordance with the specifications herein contained. The thickness, after rolling, of the various courses in each class is to be as follows:

Class	1st Course	2nd Course	3rd Course
6-inch	4 inches	2 inches	To be as
8-inch	5 inches	3 inches	hereinafter
10-inch	6 inches	4 inches	described

Each course of broken stone is to be applied as herein specified.

Note. The chief factor governing the thickness for a macadam road is the nature of the soil in the roadbed. Where the soil does not change it would not be necessary to indicate more than one thickness. Otherwise, a careful examination of the roads is necessary, and the thickness determined for each section should be indicated on the plan. Experience has demonstrated that a thickness from eight to ten inches is ample under any condition where a road can be maintained. If this thickness does not prove sufficient, it is evidence of an improper foundation, and the remedy must be sought there. The usual trouble is lack of proper under drainage. Where this is provided there need not be any excessive thickness of road covering. It has been the writer's practice on clay and other retentive soils to make about an eight-inch road; that is, the stone is spread in two layers of about five inches each, which after rolling reduces to about eight or eight and a half inches in thickness. On sandy soils, or soils containing a considerable percentage of sand, which are more or less porous, and where there is perfect under drainage, six inches of macadam has been found to be ample; the six inches being the thickness after the necessary rolling. It would require about eight to eight and a half inches of road material. The nature of the material also affects to some extent the amount of material that would be placed for road covering. Where soft limestone has to be used and the wear is consequently faster, it is better to provide an extra thickness of material.

CROSS-SLOPE.

The cross-slope for the roadbed is to be as shown on the accompanying plans, and is to have a slope of — inches to one foot.

Note. The amount of cross-slope or crown to be given to a road is a matter of considerable difference of opinion among road builders. In general, it may be said that on a much traveled road, if the traffic is distributed, the amount of cross-slope need be less than on one lightly traveled, also the harder the material the less the slope. As much slope should be given on level stretches as on steeper grades.

In some works on road construction the rule is laid down that the cross-slope should be steeper on high grades than on level stretches, so that the water will not follow for any considerable dis-

tance in the direction of the road, but reach the gutter sooner than would be the case with less cross-slope. While it is true that a cross-slope should be maintained on high grades so that the water will be carried as quickly as possible into the gutters, it is essential that the road have an equally steep cross-slope or crown on level stretches from the fact that in these places if a slight rut forms the only outlet the water has is crosswise of the road. Where the crown is flat a very slight depression will be sufficient to keep the water on the road. These puddles of water will soften the surface, and a hole will soon be formed which will become deeper and larger at every rainfall, so that quite as bad an effect is produced as would be the case if an insufficient crown were used on a steep grade. The theory that the cross-slope should be more on steep grades is correct for a theoretical road surface, but in practice these theoretic conditions are not fulfilled, and the conclusions drawn therefrom will not meet practical requirements. Generally the best results will be obtained on country roads with a cross-slope of one inch to the foot, this to apply to a width of macadam up to 15 feet. Between 15 and 20 feet the slope should vary from 1 inch to 1 foot at the sides to ¾-inch for the center half of the roadway. Not less than ⅝ of an inch to the foot should be given to a macadam surface.

TELFORD CONSTRUCTION.

Telford construction is to be used wherever directed by the engineer or provided for in the plans. The width required at different points is to be that designated by the engineer.

Note. Telford construction is much less used today than formerly. Nearly all of the old turnpikes in this country were constructed with a foundation of large stones. More recently some telford construction has been laid, particularly in New Jersey. In the best modern practice, the telford foundation finds little favor. Quite as efficient, and a much more economical construction, is effected by a layer of gravel or broken stone whenever the character of the foundation requires an extra thick road covering. It is a mistake, however, to suppose that a more stable foundation is secured by placing the large pieces at the bottom of a road covering. In case there should be any frost disturbance and consequent movement of the materials forming the road covering there is always a tendency for the larger pieces to work to the surface, whereas if a layer of material is placed with the smaller particles at the bottom, subsequent disturbances from any cause will result in little or no readjustment of the relative positions of the particles

As a telford foundation is usually expensive and exceedingly difficult to have laid properly, and does not prove practically more efficient than a cheaper form of construction, there is little excuse for using it.

The following specifications will illustrate the details of this form of construction.

MATERIAL

The first course of the telford construction is to consist of sound stone with sharp corners broken to the following dimensions: Depth from 5 to 8 inches; width from 3 to 6 inches, and length not exceeding 10 inches.

LAYING.

Broken stone for the first course of the telford construction is not to be laid before the roadbed has been made as specified. The pieces of stone are to be set by hand on edge and laid close together lengthwise across the road resting on the broadest edge. Protruding corners are to be broken off and the interstices filled with small pieces.

ROLLING.

After the stone for the first course has been laid and brought to a proper cross-section, the spaces filled with spalls and the layer made as compact as possible, it is to be rolled with a steam roller weighing not less than ten tons. The interstices must not be filled with earth.

UNEVENNESS OR DEPRESSIONS.

Should any unevenness or depressions occur during or after the rolling of the first course, they are to be remedied immediately by broken stone and rolled firm.

THICKNESS.

The thickness of the first course for telford construction is to be 8 inches when finished.

FIRST COURSE FOR MACADAM CONSTRUCTION.

Macadam construction is to be used wherever directed by the engineer or provided for in the plans. The width required at different points is to be that shown on the plans.

MATERIAL.

The first course of macadam construction is to consist of sound stone broken to sizes varying from ¾ inch to 1½ inches, no piece to have a diameter greater than 1½ inches.

No material is to be used which, in the opinion of the engineer, is unfit for the work. If any such material is put upon the road it shall be removed immediately upon notice from the engineer, and replaced by proper material at the contractor's expense.

NOTE. It is not necessary that the first or lower course of a macadam road should be of the hardest or toughest material. The purpose of the lower course is to distribute the weight of the traffic over the earth foundation, so that wherever it happens that tough material suitable for a good wearing course is remote from the place of construction, and consequently higher in price than more accessible material which is not so good, economy can be effected by using the poorer local material in the foundation course, applying the better material to the upper course only. A quality of gravel that would not make a good road surface may be used in the first course; likewise burned shale; in fact, any comparatively non absorbent, enduring material broken to a suitable size.

SPREADING.

No broken stone is to be spread before the roadbed has been made as specified.

The broken stone is to be spread upon the roadbed, prepared as herein described, with shovels, from piles alongside the road or from a dumping board, or it may be spread directly from wagons specially constructed for this purpose and approved by the engineer; but in no case shall the broken stone be dumped directly upon the roadbed.

As soon as spread, the layer of stone is to be thoroughly raked or harrowed with a tooth harrow, and finally trimmed true to the shape of the cross-section.

NOTE. It is a well known fact that a mass of various sized pieces of stone adjusts itself when stirred or raked so that the smallest sized particles are at the bottom and the largest at the top. When this conditon is attained, we have what may be called a stable equilibrium of the particles relative to one another.

Therefore, if we rake thoroughly a layer of stone, we shall adjust the pieces so as best to resist any disturbing force. As the roller goes over a layer of material thus assorted it tends to compact much more readily, as the larger pieces do not attempt to work their way through the road surface. The arrangement often seen represented in cross sections, showing the largest pieces at the bottom and the smallest on top, is a reversal of what it should be. The stability of such a mass of material may be compared to that of a pyramid resting on its apex.

It will be readily appreciated that if the pieces of rock forming a road surface have been well compacted, even though the smaller pieces are at the top, there will not be any relative movement of the pieces of stone, except that they are loosened, which will happen when frost is coming out of a badly drained road. Where such places are encountered, and there are many instances of roads practically impossible to drain properly, the road surface can be maintained much more nearly intact, if the pieces of stone are arranged with the smallest at the bottom.

But it is not sufficient merely to have a layer of the smaller screened stones as a bottom course and a layer of larger size on top. In the smaller size are pieces varying from ¾ to 1½ or 2 inches, according to the size of the screen. It is then desirable that as nearly as possible all of the 2-inch size be at the top and the other sizes arranged in this order down to the smallest.

This arrangement can be effected sufficient for all practical purposes by thoroughly raking or harrowing the layer of stone after it is spread.

There is another object attained by this method which has always been recognized as most desirable in the construction of macadam roads, and this is to have the surface composed of as nearly equal sized pieces as possible. As a macadam road surface composed of various sized pieces begins to show wear, it is observed that the largest pieces of rock protrude, producing a rough surface.

The fact that the larger the pieces of rock, the more resistant is the road surface to the action of traffic, is another reason for having

the larger pieces at the surface. There is, however, a practical limit to the size of the pieces of rock for macadam construction, varying somewhat according to the hardness of the rock and character of the traffic. The soft limestones can be screened through a 3½-inch screen and used successfully for the surface. Many hard rocks, as trap and some granite, cannot be used so large, a 2½-inch screen being the largest, unless subjected to very heavy traffic; that is, traffic made up of heavily loaded wagons.

It has also been observed that a road surface composed of small pieces of stone deteriorates much more rapidly under action of automobile traffic than when built of larger sizes. While the writer cannot offer exhaustive evidence on this point, all of his observation confirms this opinion.

To sum up what is gained by using the smaller pieces of rock in a layer at the bottom and the largest at the top, we have a more stable road, a more even, and a more durable surface.

ROLLING.

After the broken stone for the first course has been spread and raked or harrowed to a uniform thickness, and has a proper cross-section, it is to be rolled with a steam roller, weighing not less than 10 tons, until it is compacted to form a firm, smooth surface. The rolling must begin at the sides and work towards the center and the rear wheels of the roller must cover this space thoroughly.

Note. The strength of a stone or macadam road depends entirely upon the rigidity with which one piece of stone is held against its neighbors. The roller presses the piece of stone close together so that instead of having a contact of but one point or one edge with a face, the faces of the pieces of stone are brought together and the voids as they exist in the loose material are reduced from 45 per cent or 50 per cent to about 20 per cent.

It is bad practice to fill in the voids in the stone with fine material before rolling, as it prevents the pieces of stone being keyed firmly in place.

There does not appear to be any valid reason for filling or bonding the lower course of material at all, and is so much work wasted. A roller should be run slowly, not over two miles an hour. The slower the roller is run, the more firmly are the stones compacted. It is possible to run a roller so as to tear a layer of stones to pieces.

UNEVENNESS OR DEPRESSIONS.

Should any unevenness or depressions appear during or after the rolling of the first course, they are to be filled immediately with broken stone and re-rolled until a firm, even surface is obtained.

Note. A depression in a layer of macadam should be filled with material of the same kind and size as that composing the layer. If a patch of small material should be added to bring up the surface composed of large pieces, the small pieces would be ground under traffic, and the depression would again appear. The proper way is to loosen the surface in the depression, add extra material of the same size, and re-roll.

THICKNESS.

The thickness of the first course of broken stone, after thorough rolling, is to be that of the class of macadam construction specified for any particular place as described.

If, for any reason, a greater thickness than specified is made by the contractor, no extra allowance for such additional thickness will be made.

SHOULDERS.

After the telford foundation or the first course of broken stone or gravel, as the case may be, has been made as herein described, earth shoulders are to be constructed along each side of the road for a width of at least four feet, as shown on the accompanying plans.

Against these shoulders is to be spread the broken stone for the second course as herein described. The shoulders are to contain a sufficient quantity of earth so that a smooth and continuous slope will be obtained after the shoulders and second course are rolled. The shoulders with the......feet of stone will make a total width of......feet to be shaped with a cross-slope of ......inches......to 1 foot.

Material for the shoulders must be free from roots, stumps or other vegetable matter and thoroughly compacted by the roller. Material with such a proportion of sand, as prevents it, when dry, from compacting readily under the roller, is not to be used.

No material which is considered unfit for the work by the engineer is to be used, and, where any such is put on the work it shall be immediately removed, at the contractor's expense, upon notice by the engineer.

Note. It is important to have the material for the shoulders put in place as soon as the first course is made, as the shoulders are depended upon to hold the second course of material in place. The shoulders should be shaped before they are rolled, so that they will be, depending on the nature of the material, from 2 to 3 inches higher than the second course of broken stone; and when they are rolled they will press down even with the surface of the broken stone. As the work progresses, the height that it is necessary to keep the shoulders above the broken stone so that they will roll down properly, is very readily ascertained. If it is found that not enough material has been used, more must be spread until the shoulders are brought to a proper shape. If the road bed for the new road has been cut sufficiently deep, it will not be necessary to fill in extra material for the shoulders. Where the shoulders are thus made, by cutting out, it is advisable to leave them a little high at first, and then pare them down with a road machine. After a little experience a good operator can trim the shoulders very accurately by this method.

An excellent plan is to sow the shoulders with grass seed. The sod forms a good protection to the shoulders, besides adding much to the appearance of the road.

BLIND CROSS DRAINS.

Blind cross drains are to be constructed at intervals of 50 feet on each side of the road in the following manner: They shall run approximately at right angles to the direction of the road and shall be cut to a sufficient depth so that the water can readily run from the surface of the subgrade to the side of the road. They shall not be less than 8 inches in width. These drains are to be shaped just before spreading the first course of material and are to be filled with broken stone. These cross drains are to extend to the gutter. The stone in the cross drains shall come within 3 inches of the finished surface of the shoulder.

NOTE. The blind cross drains are necessary wherever the shoulders are made of an impervious material. These cross drains are particularly useful on level stretches of the road where satisfactory longitudinal drainage is difficult to secure. Roads constructed through lowlands, which may be submerged by occasional floods, should be well provided with these blind side drains. In such instances they should be put in at intervals of about 30 feet. The pitch or grade to these drains should be the most that can be obtained from the surface of the subgrade to the bottom of the gutter. They also serve to keep the shoulder well drained, and consequently firmer in wet weather. The side drains are especially useful during construction to drain the roadbed rapidly after a rain, which easily penetrates the loosely spread material, and softens the subgrade so that work has to be abandoned on that section until it dries out.

SECOND COURSE FOR MACADAM CONSTRUCTION.

The second course of the macadam construction is to be the same width as the first course.

MATERIAL.

The second course is to consist of stone broken to sizes varying from 1½ to 3 inches; no piece to have a greater diameter than 3 inches.

Unless otherwise specified, the rock shall have a "coefficient of wear," as determined by the Duval test, of not less than 15.

NOTE. It should be borne in mind that the second course, or the course covering the foundation of either macadam or telford construction, is the one which must receive the wear from the traffic. The foundation course merely gives the thickness so that the pressure of traffic may be distributed over the natural earth roadbed, which supports the road surface. Therefore, in making specifications for the second course of material, its purpose should be kept constantly in mind. Inasmuch as the wear due to the traffic is dependent on so many different conditions, it will be natural to expect that which is best in one instance may not prove equally successful in other cases.

The wear due to traffic is of two kinds: That of horses' hoofs, and that from the grinding of wheels. These produce different effects on broken stone roads. Where the traffic is very heavy; that is, where the weight upon the wheels is great, their pressure tends to compact the stone firmly, which if it is not of sufficient strength, will be crushed and ground to dust. On the other hand, where the kind of traffic is lighter, with wheel pressure comparatively small, there is but little grinding or compression. Generally this lighter traffic moves more swiftly so that the effect produced by the horses' hoofs is much more noticeable. The hoofs of a fast running horse hit the road with a quick, hard blow, which has the effect of loosening the particles of broken stone. As there is little compression given by the wheels in this class of traffic, the loosened pieces of stone are not pushed back into place, and this results in what is known as "raveling."

The action of motor vehicle traffic on a macadam surface is far more destructive than any other to which our roads are subjected. Careful observations made by the Office of Public Roads at Washington show that the destructive action is almost wholly due to the driving wheels. The scour or shear on the road surface that is produced when heavy cars are driven at high speed is sufficient to displace the surface particles of the road which are sucked up and dispersed in clouds of dust. The stones in the upper portion of the road are bared and, in time, loosened. The surface of the road, particularly in dry weather, becomes covered with pieces of loosened stone.

Experience has shown that different varieties of stone act differently under traffic. Thus, some varieties will make a hard, firm road if there are many vehicles moving over the road; while other varieties are found to be quickly ground into dust under similar conditions but give good results where the traffic is lighter. The heavy traffic is found to require a hard, tough stone, with a high power of resistance to wear, and which will require great force to split. There are few varieties of rock which have these physical properties that are not adapted for the surface of a macadam road which will be subjected to a large amount of heavy traffic. Such traffic is not usually found on the majority of country roads, or, if found, there is seldom a sufficient amount of it to keep the hardest varieties of stone in place unless they have a third physical property, that of binding readily. Such stone when ground to dust will cement together, and this property is called its cementing value. If this property is wanting or exists only to a slight degree in a rock, it will be found practically useless to suply such material to the ordinary country road. And in proportion as the traffic over one road is lighter in character than that of another, so too should the cementing value of the material used in the former case exceed that used in the road with heavier traffic.

The road builder is often confronted with the problem of how best to use a comparatively soft material under conditions which require the hardest variety of rock, or at least where such rock could be used to advantage. The same material can produce under the same conditions quite different results according to the way it is handled. For example, the amount of wear which a road can sustain can be greatly increased by a change in the size of the pieces of broken stone which make up the second or wearing course of the road. A soft limestone or other variety of rock having a low resistance to wear should be broken in larger pieces than harder material would be used; that is, the second or wearing course should consist of the larger sizes, which are larger for softer varieties of stone than for harder varieties. A soft variety of rock used to best advantage may make as durable a road as a harder variety of material improperly used.

It is, therefore, advised that all rocks which have high cementing value but small resistance to wear (that is, having the coefficient according to the Duval test of less than 10), should have the two and three-inch pieces placed in the second course. The sizes permitted

may be slightly larger in all courses for rocks with high cementing value and low wearing qualities. Thus, the crusher could be opened wider and more material put through in a given time, which would cheapen its cost, and, therefore, in a measure offset the additional cost of maintenance, which might be necessary where a rather soft variety of rock was used with a moderately heavy traffic.

The fact that pieces of rock from two to three inches in size will lock or key together more firmly than one-inch size makes a surface composed of the larger sizes resist more effectively the action of automobile traffic. In many instances observed by the writer it has been noticed that the first place to give way has been where there evidently has been a cluster of finer particles.

Reference has been made to the Duval and othr tests of road material. It is, perhaps, sufficient here to say that a full description and discussion of the tests are found in the bulletins of the Office of Public Roads, Washington, D. C., which may be had on application. The road builder is, however, not often given an opportunity to make much of a selection of materials; he must use what is at hand and make the best of it; so that there is but a limited field of application for the deductions from the refined methods of the laboratory. But even with a single source of material, it is valuable to have thorough laboratory tests made, which should be compared carefully with the practical service tests, as it is only by such comparisons that intelligent interpretation of the laboratory results are possible. Occasional tests will detect any variation in the rock used; they also give valuable information as to what part of a quarry, not uniform in its rock, yields the best material for this service.

SPREADING.

The broken stone for the second course is not to be spread before the foundation or first course has been completed and shoulders made as herein specified.

The broken stone is to be spread upon the first course, prepared as herein described, with shovels from piles alongside the road or from a dumping board, or it may be spread directly from wagons, especially constructed for this purpose and approved by the engineer; but in no case shall the broken stone be dumped in piles directly upon the first course unless it is entirely rehandled.

As soon as spread, the layer of stone is thoroughly raked or harrowed with a tooth harrow, and finally trimmed true to the shape of the cross-section.

Note. The object of having the stone spread in the manner specified above is to secure a uniform amount of stone for any given area; so that when compacted by the roller it will compress evenly at all points and no humps will be formed, as will be the case if the stone is dumped in a pile from a wagon and raked outwards in all directions until apparently spread to the required thickness. For in the center of every pile of stone so dumped there is a core formed where the pieces have been more closely jammed together by the weight of other pieces on top of them, so that when the roller passes over the stone there will be formed little mounds wherever these com-

pacted cores were made, which no amount of rolling will efface. It may not be practicable to have the stone dumped at the side of the road or to have a dumping board at hand, and it would then be necessary to permit the second course of stone to be dumped upon the first course, in which case care should be taken to have the pile of stone raked or shoveled over so as to loosen all parts of it equally.

ROLLING.

After the broken stone for the second course has been spread to a uniform thickness, and has a proper cross-section, it is to be rolled with a steam roller weighing not less than ten tons until it is compacted to form a firm, smooth surface.

The rolling is to begin at the sides, the shoulders first being rolled firm. When completed the surface of the shoulders and of the second course of broken stone should be smooth and continuous with a cross slope of...... inches to 1 foot.

If any unevenness or depressions appear during or after the rolling of the second course, either on the surface of the shoulder or the broken stone, suitable material shall be added to remove all such unevenness or depressions, earth being used on the shoulders and stone for the broken stone surface.

THICKNESS.

The thickness of the second course of broken stone, after thorough rolling, is to be that of the class of macadam construction, specified for any particular place, as described under 6-inch, 8-inch, and 10-inch macadam. On a telford foundation the thickness shall not be less than 4 inches.

If for any reason a greater thickness than specified is made by the contractor no extra allowance for such additional thickness will be made.

Note. The second course must be rolled until every particle of stone has been wedged firmly against its neighbors. Satisfactory results cannot be obtained if too great a thickness of stone is rolled at once. Not over 6 inches measured loose should be attempted. There are many varieties which will not compact readily, and give great trouble in rolling. No specific directions can be given which will prove applicable in every case. If the conditions are such as to make it imperative to use material in which there is considerable mica, it will usually be found necessary to sprinkle it lightly with sand and water to prevent the stone creeping as the roller passes over it. Frequently poor results are caused by attempting to operate the roller at too great a speed, for material which is hard to manage may often be easily handled by reducing the speed of the roller to a rate of about one mile an hour. It may sometimes be necessary, even then, to use a little sand or stone screenings to hold the material in place so that the pieces of stone will be compacted and not grind one another into rounded fragments. But little trouble of this sort is experienced with the softer varieties of rock. The danger in such cases is that the road may be rolled too much. This can be readily told by watching the pieces of stone on the surface; if they are being crushed or broken, the rolling should not be continued. This applies particularly to the softer varieties of limestone.

It is necessary in shaping up whatever uneven places may appear

to use material of exactly the same character as that of which the surface is composed. The earth should be filled up with earth, and broken stone with broken stone of the same size. If the depression is so slight that a single thickness of the broken stone is too thick, the way to fill such a depression is to loosen the surface all about it and add a small amount of broken stone, and then roll the whole down. A little experience will soon show about how much higher the loosened portion should be in order to roll down to the required surface.

THIRD COURSE FOR MACADAM OR TELFORD CONSTRUCTION

The third course of macadam or telford construction is to consist of rock screenings varying from dust to one-inch pieces. The screenings are to contain all of the dust.

NOTE. If the material of which the screenings are made (which would usually be the same as that of the second course) is extremely hard, that is, has a Duval co-efficient of wear of 20 per cent or over, the size of the largest pieces should not be over a half inch. If softer material is used, the screenings may contain pieces as large as one inch in diameter.

The screenings from some varieties of rock are extremely difficult to work properly; that is, they do not seem to bind together and, after rolling, when dried out, loosen and do not hold the surface of the road as it is desired. For example, there are some crystalline limestones, a number of which are found in this state, particularly the stone at the State Prison used by the State Highway Commission, which do not bind with any facility. The laboratory tests also show it deficient in cementing quality. It is found, however, that when this dust is combined with silica the combination produces a material which binds very much better than either one alone. This fact was observed on roads which had been sprinkled with a light covering of gravel or coarse sand. An investigation in the laboratory combining silica with such limestone dust also showed an increase in cementing power. In all of the construction carried on by the State Highway Commission the past year we have advised, where the material from the Joliet prison has been used, that it be bonded with a thin layer of fine gravel or very coarse sand; where this has been done the result has been very much more satisfactory than where roads were built using the natural rock screenings alone.

SPREADING SCREENINGS.

After the second course of stone has been rolled and completed as specified, the screenings are to be spread, but in no case are screenings to be used until the second course has been thoroughly rolled and compacted. The screenings are to be spread dry with shovels from piles along the road, or from dumping boards, but in no case are the screenings to be dumped directly on the second course. The quantity of screenings used is to be such as will just cover the second course.

NOTE. There usually seems to be a strong inclination to put on screenings too thick or too much at one time. The road surface apparently is finished quicker and with less work where a layer of screenings from three-quarters to one and a half inches thick is spread at one time.

Where it is desirable, as on park roads, to have a soft surface, a greater layer of screenings may eventually be placed, as such roads naturally receive or are expected to receive, constant attention, and can thus be maintained in good condition. In general, however, it is a safe rule to use as few screenings as possible. A road with too much screenings will have a deadened sound as vehicles move over it.

WATERING AND ROLLING.

After the screenings are spread they are to be sprinkled with water from a properly constructed sprinkling cart, and then rolled with a steam roller weighing not less than ten tons. The amount of water necessary is to be determined by the engineer. The rolling is to begin at the sides and to continue until the surface is hard and smooth and shows no perceptible tracks from vehicles pasing over it.

If, after rolling the screenings, the stone appears at the surface, additional screenings shall be used in such places.

The rolling and watering shall continue until the water flushes to the surface. The rolling is to extend over the whole width of the road including the shoulders.

NOTE. The best results are invariably obtained if the screenings are first wet and then rolled. Often it will be impracticable to get a sufficient supply of water to the road for this purpose, in which case the screenings may be spread and the road used as little as possible until a shower does the sprinkling. As soon as it is possible, either during the shower or immediately after, the rolling should be started, and continued until the surface of the road has become practically impervious to water. Where it is necessary for the road to be used as soon as the screenings are spread, and it is impossible to water them, they may be partially rolled dry and then another layer of screenings spread. This excess of screenings will make the road somewhat more dusty or muddy, according to the weather, and the surface will require more careful watching than is the case where the screenings are sprinkled before rolling. Care should also be taken not to drench the screenings at first, as the water will go immediately through the loose stone of the road into the foundation, softening it, and rolling will have to be suspended until it dries out. The first sprinkling should, therefore, be light—merely enough to permit the dust to bind or cake together. The screenings should be added a little at a time so that they will fill all interstices thoroughly, but not form a crust on the road, which is liable to disintegrate and peel off. As soon as the interstices are thoroughly filled with the screenings, and consequently made impervious to water, the sprinkling may be heavier than at first. Where the roadbed is on a gravelly or sandy soil which is naturally well drained, but little dam-

age will result from copious sprinkling; but where the roadbed is on a clay soil care must be exercised if the foundation is to be kept firm enough to support the roller without jamming the broken stone into the earth, which would result in an uneven place in the road-surface.

UNEVENNESS AND DEPRESSIONS.

If any unevenness or depressions appear in the road surface after rolling the screenings, broken stone and screenings shall be used until they are removed and the finished surface conforms to the proper cross section, as shown on the accompanying plans, and presents a smooth, even appearance.

NOTE. The following directions concerning the application of screenings were prepared by the writer for the use in the work of the Illinois Highway Commissioin:

Screenings must not be dumped directly on the broken stone but must invariably be placed at one side of the roadway.

The shoulders must be shaped and rolled for two or three feet from the edge of the stone, the surplus earth then being graded off towards the gutter and the shoulders re-rolled, not less than five feet where conditions will permit. This will make a firm, smooth space on which to deposit the loads of screenings.

The last course of stone must be thoroughly rolled until the stone has compacted, and each piece is in contact firmly so that the stone does not jar or move when wagons go over it. When the stone is thus firmly packed, the screenings are to be spread, not by shovelfuls in a place but by having each shovelful spread parallel with the road from a square point shovel over the greatest area posible. The first application should be just enough to fill the interstices between the stones. The screenings should then be very lightly sprinkled. Where the screenings have been washed down between the stones, a very light additional layer of screenings should be put on. Then have the roller pass over the work, beginning at the edges and working towards the center, once over every part. Where necessary, add more screenings and again roll.

If a gravel binder is used, see that the screenings fill the interstices only partly, then spread on some of the gravel binder. After the first rolling, put on where necessary more binder, and then sprinkle lightly.

The screenings or binder, after this sprinkling, may stick to the wheels, and it is better, therefore, to do this sprinkling the last thing at night, and roll the road in the morning. After this rolling, and adding what binder may be necessary here and there, the road will probably be sufficiently water tight so that more water and binder may be added. As soon as the road becomes water tight it should be well sprinkled, if possible, having the water play on the roller wheels. The screenings or binder must be placed on the road and that part of the road finished immediately and traffic blocked off until the road has taken on a set.

Unless the work is done in this way, it will be found that the road when partly screened, and travel allowed to go upon it, will become

loosened. The screenings will get between the stones and entirely surround many of the pieces of stone in the top of the road. Where this happens, it will be found that they will easily pick out. This explains why it is that we find occasionally patches here and there where the stone picks out readily after we have finished the road.

Travel over broken stone before the screenings are added does no particular harm, but screenings must not be put on crushed stone that is loose, and after screenings are placed, that part of the work must be finished immediately before allowing any other travel to come upon it.

PRICE PAID FOR MACADAM OR TELFORD CONSTRUCTION.

The price herein agreed upon to be paid for macadam or telford construction is to include all work and materials necessary to do the work as herein specified.

NOTE. There are two methods of payment for macadam work in general use. One is by the cubic yard or ton for broken stone; the other by the square yard or unit of surface of finished road of a given thickness. The advantages of the unit quantity method—that is, payment by the cubic yard or ton of broken stone used, are payment for material actually used, and no inducement for the contractor to skimp the work. The advantages of payment by the unit surface measurement are ease of ascertaining the amount of work to be paid for, and the throwing of all responsibility for improper construction of the roadbed upon the contractor, who must supply at his own expense any extra material that may be necessary to bring the road to a proper surface through any lack of care in the construction of any portion of the road.

By either method, careful supervision is important though it is not so necessary to have an inspector as constantly on the work when paid for by the surface unit as by the quantity unit. In the latter instance someone must be at hand to note every load of stone which is placed on the road, and to see that every load of stone credited to the contractor is actually employed on the work.

On the other hand, by the unit surface measurement method, it is necessary to be on the constant watch to see that an unscrupulous contractor does not put in a less amount of material than the specifications require. There is, however, a very good safeguard against this as the road can be dug up occasionally and measured to ascertain that the proper thickness has been made.

The measurement of broken stone by the cubic yard or wagon leads to constant trouble in securing a full loaded wagon. There is also the question as to where a wagon load should be measured. If the specifications call for a cubic yard of broken stone deliveerd upon a road, the contractor must estimate how much shrinkage there will be in a load of stone due to settlement from jarring received in traveling to the work. The amount of settlement will necessarily vary with the distance of the haul and roughness of the road. This makes the actual amount of material to be furnished by the con-

tractor somewhat indefinite; so that, unless it is possible to weigh the broken stone, the unit surface measurement is advised.

The results from a series of tests conducted by the writer to determine what is the settlement of crushed stone, and what is the consequent weight of a cubic yard of crushed stone under different conditions, will be found in the report of the Illinois Highway Commission for 1906, page 75. These tests show that there is a variation according to the method of loading the wagon, whether the stone was dumped from a considerable distance or merely shoveled into the wagon; that, after hauling for eight or nine hundred feet, about all the settlement that had occurred had taken place; that the variation in the weight of a cubic yard seemed to be from 2,400 to 2,600 pounds; that is, a cubic yard weighed 2,400 pounds before the settlement occurred, and, after the wagon had gone over the road, weighed about 2,600 pounds.

There was also a large number of observations made on the settlement of limestone in carload lots, the amount of settlement corresponding with that observed in wagon-loads. As a result of these tests, the Commission adopted the arbitrary value of 2,500 pounds as the weight of a cubic yard of crushed limestone. The limestone on which these tests were made has a specific gravity of about 2.70.

The per cent of voids in a yard of crushed stone varied according to the method of loading or the height from which the stone was dropped. When dropped from 20 feet the voids in 3-inch stone was 41.8 per cent, varying to 48.7 per cent when loaded with shovels. The 1½-inch size showed a variation of 42.5 per cent to 50.5 per cent. The ¾-inch size or screenings showed a variation in voids of 39.4 per cent to 44.6 per cent, so that it is evident that there is only one way in which to buy crushed stone, and that is by weight. We could, of course, assume arbitrarily so many pounds as being a cubic yard, which would be near enough, perhaps, to make estimates for quantities where the cubic yard is the unit measure.

The writer has usually preferred the unit surface measurement as the basis of payment as the more satisfactory for the conditions usually encountered in country road building.

Discussion.

President Loweth: What kind of stone is usually considered the best for macadam road construction? Trap rock, granite, and limestone are mentioned; but, assuming that all of these are equally available, in what order should preference be given?

Mr. Johnson: Where it is possible to make a choice, the kind of stone to be used depends upon the traffic. I recall an experience with a road in Nantucket where trap rock was used. There was not enough traffic to keep so hard a material in place; whereas, a much softer limestone held in excellent shape, so that in this instance a softer rock was found to be better.

Whatever kind of rock is used it must possess a certain amount of binding quality that will assure us it will hold its place after

the road is completed. I do not believe, however, it is possible to determine absolutely what is the best material until all conditions are known.

Mr. F. M. Button: What can be done to repair an ordinary macadam country highway that was laid but never rolled, and which has become full of ruts?

Mr. Johnson: We usually loosen the surface, put in enough material to even the shape of the road, and then roll it. I am not sure but that it would be cheaper in the end first to put material on loosely and, if rolled at all, roll but very little, allowing the traffic to go over it for a time and make what it will out of it.

The traffic will of course stir the material up until the larger pieces come to the top, and when the road is finally compacted it will be very solid.

The next spring loosen the surface, add some more material, roll it, and we shall not have the same difficulty from ruts. The new surface will wear better than roads that have been built from the ground up. The explanation is that the vehicles over that road will compact the material firmly where the ruts usually form, so that thereafter no ruts will form due to the compression of the layer of stone under the wheel track. If only a small amount of machinery is available, it might be worth while to let the traffic take care of the road at first and use the roller chiefly in re-surfacing after the road has gone through the first winter.

Mr. E. N. Layfield, M.W.S.E.: The Chicago Terminal Transfer R. R. Co. has done some macadam work in connection with track elevation work, and, I am sorry that we did not have the advantage of having Mr. Johnson's paper before the work was started. It might be of some interest for me to refer to one or two points in connection with one method of handling it.

The roadbed had been lying there for a year, and it was sufficiently hard to make it unnecessary to roll it. The conditions were such that we could lay a track on this street and we unloaded twelve inches of blast furnace slag on it. Our choice of material was influenced by a number of reasons, the principal one being the availability of the slag at a proper price. We put twelve inches of it on the roadbed and covered that with sand, in which there was a little clay. This we got from one of our sand pits, and it made an excellent binder. This was rolled very thoroughly with a ten-ton steam roller. The conditions were favorable, because we had our own cars and could run them on the work. After the slag and clay binder were rolled to our satisfaction we brought in on our cars the stone, which ran from 2 to 2-½ inches in size. All this material, was brought in on 100,000 pound cars with swinging sides, so it could be unloaded very economically. This stone was unloaded beside the track and it was necessary to place it in piles, which, under the circumstances, could not very well be avoided. After we unloaded the stone along the track as high as we could,

in order to get the cars out, we ran a Jordan spreader through it and spread the material to a width of sixteen feet. This of course did not give the thickness required for the work; we made that four inches. We used bricks, turned them on edge and leveled the stone off to the top of the bricks, the top of the slag being very smooth and neat. After we had a four-inch course spread, we placed limestone screenings on top of that, putting them on very thin, and we had the men throw additional screenings from piles along the track into the places where it worked down, as the roller went over it. We got a very smooth surface without any excess screenings on top.

A Visitor: Did I understand you to say that the cost of maintaining a road is about $90.00 per mile per year?

Mr. Johnson: It is very difficult to say what the maintenance cost will be as we have so little exact data to work upon, but I believe $50.00 to $75.00 per mile should be ample on an average.

Mr. Button: What is the average cost per mile of a road, say, 12 feet in width and 8 inches in thickness?

Mr. Johnson: An 8-inch road contains practically 3200 tons per mile of limestone, showing the cost of our material; that fixes this portion of the expense. The labor cost, where the stone is shipped by rail, of unloading material, hauling, spreading, and doing all incidental work, should average inside $2000.00 a mile where the haul does not average over a mile. We have built roads for $1600.00 to $1700.00 per mile. On the other hand, if the shipments are irregular and there are delays from different causes, the cost has risen as high as $3000.00, as it was impossible under these conditions for the work to proceed to advantage.

Mr. Miles E. Nixon: In the second paragraph of specifications (Roadbed) there is a statement "if sandy or other soil be encountered, which will not compact readily under the roller, a small amount of clay or other means should be used until a firm, hard surface is obtained after rolling." I would ask Mr. Johnson what other means we have to accomplish this result.

Mr. Johnson: In one instance I know that $750.00 per mile, was spent for cotton cloth, which was laid upon the sand. Straw also can be used for the same purpose. The object is to hold the sandy foundation in position long enough to permit a layer of stone to be placed and rolled, after which there is no further difficulty.

Mr. Nixon: It is said that in many cases, the limestone used from the Joliet neighborhood, would not properly bond but could be made to do so by the addition of sand or gravel. Is it not generally accepted that this bonding is due to hydration and perhaps some other disturbance of atomic arrangement? I do not understand how silica can produce or augment this change.

Mr. Johnson: So far as I know, I do not understand that chemists have been able to find definitely the cause for this phenomenon.

which, however, is a fact. The Joliet limestone has this peculiar quality. It will at first set and the bond appear to be all right but the next considerable rain will loosen the screenings, which apparently slack, and the bond is lost; while with material which bonds properly, the next rain will make it bond all the better. The same thing has been noted in the laboratory in connection with tests made from certain kinds of stone. Some stood the treatment of placing in water while others would collapse. The Joliet limestone when mixed with sand or fine gravel bonds extremely well. A more detailed discussion of this phase of the work can be found in the bulletins of the U. S. Office of Public Roads.

Mr. D. W. Roper, M.W.S.E.: I would ask if there is any great difference in the quality of the several varieties of stone available in this state and, if so, which are the better?

Mr. Johnson: There are comparatively few varieties. Around Rockford, they are using a limestone which has a certain amount of silica in it. That material with very little rolling, will make a better road than some of our other limestones when well rolled.

In the State quarry at Joliet we are now down about 40 feet, and have gone through five distinct layers, which appear different on the roads and also in the laboratory tests. So far as wearing qualities go, the tests show they are not very dissimilar, but there is a great difference as to the bonding quality. Some of the limestones will not bond together while others make an excellent road with very little trouble.

In the extreme southern part of the state, are vast quantities of novaculite, which is extremely hard and brittle. It makes, however, a very good road, and has been shipped extensively for use on roads about Jackson, Tenn.

President Loweth: I think, Mr. Johnson, we would all be glad if you would give us a brief resume of the work of the Illinois State Highway Commission; in what parts of the state has it done the most work, and how does it determine when roads will be built? Are the roads built by the Commission paid for by the state or partly by the state and partly by the local community?

Mr. Johnson: I fear it will take too long a time this evening to answer very fully the questions your President has asked.

The State Highway Commission has been given an appropriation to carry on experimental work in road and bridge construction. We use our discretion as to what we call an experimental road and how we shall do the work. We have bought six outfits —road rollers and sprinklers—which, combined with the crushed stone, makes our contribution to any particular piece of road—a very considerable part of it.

We say to the local people, if you are particularly interested in this experiment, we will come here with the machinery, with the men to run the machinery, and material delivered to you, you to pay the freight and we to do the work. We call these experimental

macadam roads. Then the question is to be considered by the community from an economical standpoint, whether the road will be worth anything to them.

We hold ourselves in readiness as far as we can to work out the particular problem the community has if they want assistance. If they have a bridge to build, we design it, make their specifications, and try to give them a well built bridge at a reasonable cost. Heretofore the road officials have been up against it. They did not know anything about a bridge; all they could do was to go out and if, after tramping over and looking at the bridge, it seemed strong enough, they would decide to accept the work and pay for it.

We have laid special stress on concrete bridge construction. The design for a concrete bridge that we recommend for all spans under 50 feet, is one we have developed in our office. It is a through girder, re-inforced concrete structure, which is particularly well adapted to situations where there is not much headroom, and where the roadway does not need to be over eighteen or twenty feet in width.

It is necessary to put in but a few of these concrete bridges for the public to appreciate their value. We have devoted about half our time and appropriation to bridge work, and this is not an unfair division, as about half of the road and bridge tax now spent in the state is spent for bridge work.

We have built a concrete bridge at the Southern Penitentiary for testing purposes alone. It is a 40-foot span, through girder type, with an 18-foot roadway. It was built by convict labor, so that the expense to the state was nothing outside of a small amount for the necessary material. We have planned an exhaustive series of tests, which should demonstrate many points in the design of these bridges, which are today regarded more in the light of theoretical assumption than upon the sound basis of precise experimentation.

In connection with the subject under discussion tonight, the traffic census we have been taking will prove interesting. When road improvement is first considered, the question arises, "Can the community afford it?" It seems to me if that question is to be answered at all precisely, in dollars and cents, it can be done only by measuring the use that the community makes of a road.

Now, the use the community makes of a road will be shown by the number of vehicles that go over it. In seventy-one (71) places througout the state we have counted every eight or ten days during the past two years the number of vehicles that go over these roads. It is the first time in this country that a systematic traffic census has been taken to find how much country roads are used. Every vehicle that goes over the road represents a certain value to the community, from the fact that somebody is making use of it. Passenger vehicles may be taken as a measure of the social side, and wagons represent the commercial side of the question. We

are not, therefore, so much concerned with tonnage as the number of vehicles. One hundred (100) vehicles a day represent a moderately traveled country road.

Let us attempt from this number to estimate what such an amount of travel gives as the worth of the road to a community. We have a certain basis for doing this from the experience gained in those communities where there are toll roads. The charge made for a two-horse vehicle is often three cents per mile, and seldom less than 2 cents, but I have found that the people in those sections prefer to pay the toll than to have their roads taken away from them. I think most anyone would be willing to pay a cent to ride for a mile over a good road.

Taking then one cent per mile per vehicle as a basis for our calculation, 100 vehicles per day throughout the year would make the road worth $365.00 per year; this is four to six times what it would cost, ordinarily, to maintain a mile of the best macadam road, so that with a traffic of 100 vehicles per day, there is no question about the worth of macadam road construction to a community. There are many communities in different sections of the country where the traffic on the average does not exceed 50 vehicles per day, but where fine roads have been built and are considered worth all they cost.

Any attempt, however, to compute the worth of roads solely on the tonnage hauled and the cost of hauling to the farmer, can not warrant usually the expenditure necessary for any very extensive road improvement. Although there have been a great many figures published on this basis alone, attempting to show that there would be a great saving, the figures I believe are based upon erroneous assumption as to the actual cost to a farmer for hauling, so that when analyzed from his standpoint, they do not appeal to him, and he therefore feels that road improvement may be a doubtful investment. But the commercial value is to my mind but a small part of its value. The farmer does not have the telephone solely because of its commercial value; he does not expect to raise any more corn because he has a telephone in his house, but he is willing to pay for the telephone because it is an added convenience to his life; and, on the same basis, communtities are willing to pay for public improvements, not because they expect to make a great deal of money, but because it will make life a little more comfortable and better worth the living.

Therefore, if we can find any way to express what this value is to a community, we can see easily how it is that road improvement is carried on, and rather than going backward, where once begun it is always pushed ahead. It is a convenience which, when once experienced, a community henceforth demands.

Mr. Layfield: The C. B. & Q. Ry. Co. has just built a railroad bridge over Sixteenth St. similar to the one you have been speaking of.

President Loweth: Are the experimental roads always built of Joliet limestone?

Mr. Johnson: No, other grades of limestone are made use of.

Mr. E. E. R. Tratman, M.W.S.E.: I have been told by English road engineers, that where hard stone is used, the engineers aim at producing a mosaic appearance, with the individual stones exposed to view instead of concealed by mud or dust. This appearance is taken to indicate a good road. Furthermore, in some sections of that country the traffic is properly distributed over the road surface, while in this country it is usually concentrated at the middle of the road, teams turning out only to pass other teams. This causes undue wear of even the best roads. There is a style of macadam paving now under construction, in a town near Chicago, which differs essentially from that covered by Mr. Johnson's specifications: (1) the roadbed is rolled; (2) the coarse bed of stone is laid (but not rolled); (3) a bed of screenings is laid, sprinkled and rolled; (4) the road is opened to traffic as soon as it is dry, in order to let traffic work the screenings into the coarse stone: (5) after some weeks, another layer is spread, sprinkled and rolled, completing the work. The consolidation by traffic is ineffective, as the traffic is confined to the middle of the road, where the screenings are soon crushed to fine dust that becomes a nuisance, while the sides of the road are left undisturbed. On part of this work gravel has been used as a binder, and was given a much heavier sprinkling than the screenings. These roads appear to be more compact and less dusty than where the screenings alone are used. Lack of maintenance, I think, is the great cause of trouble with our country roads. I notice that the specifications presented by Mr. Johnson, provide only for screenings, and that he makes no use of gravel binder. It seems to me that gravel is a better binder than the stone alone.

Mr. Johnson: We have used the gravel binder and recommend it. It will bind together and give a much better bond than limestone screenings alone. With every road that we build out of the Joliet stone, we insist that a fine gravel binder be used.

President Loweth: Not long since I was on an electric railway about fifteen or twenty miles out from Cleveland, Ohio. I noticed that the highway along which the electric car was running was paved with brick for a strip about ten feet in width and for several miles in length, and was one of the main-traveled highways into Cleveland. It was not located in a residence or suburban district, but one covered with small truck and fruit farms. It was evening and there was a constant procession of vehicles passing in a direction away from the city, and doubtless in the morning the travel was mostly in the other direction.

It would appear that the character and extent of the traffic, in this case, justified a narrow strip of brick pavement on a country road.

PROCEEDINGS OF THE SOCIETY.

MINUTES OF THE MEETINGS

REGULAR MEETING, Wednesday, November 4, 1908.

A regular meeting of the Society (No. 642) was held Wednesday evening, November 4th. The meeting was called to order about 8:30 p. m., with President Loweth in the Chair, and about 35 members and guests present. The reading of the minutes of the meeting held in October was dispensed with, by consent, as they had been published in the Journal. The Secretary reported from the Board of Direction, that applications for membership had been received from:

	Grade.
James Robinson Scott, Jr., Chicago	Junior
Ralph Budd, Colon, Panama	Active
Alex. Hugo Bleuel, Chicago	Junior
W. L. Thompson, Las Cascadas, Canal Zone	Active
H. Bertram Watters, New York, N. Y.	Active
Ray E. Pauley, Sioux City, Iowa	Active
Charles Henry Clare, Chicago	Active

The Secretary announced the recent death of Charles A. Smith, of Chicago, on October 20th, and Ossian Guthrie, also of Chicago, on October 25th. Mr. Isham Randolph offered a motion that the Chair appoint a committee to prepare the usual memorials, to be printed in the Journal. This motion was carried.

There being no further business to bring before the Society, the President introduced Col. C. McD. Townsend, M.W.S.E., of Detroit, who presented his paper on "The Improvement of the Upper Mississippi River Between St. Paul and St. Louis—the Work of the National Government." This was illustrated by lantern slide views. Discussion followed from the President, Maj. W. V. Judson, Messrs. Isham Randolph, C. L. Strobel, D. W. Roper and Maj. T. H. Rees.

The meeting adjourned about 10 p. m.

MINUTES OF ELECTRICAL SECTION, November 13, 1908.

A regular meeting (No. 36) of the Electrical Section (being No. 643 of the Society) was held in the Society rooms Friday evening, November 13th, 1908.

The meeting was called to order about 8:25 p. m., with D. W. Roper, Chairman, presiding and about fifty members and guests present.

The reading of the minutes of the preceding meeting was dispensed with by approval.

At the request of the Chairman, the Secretary called attention to the rules of the Electrical Section and particularly to that paragraph providing for the nominating of officers of the Section for the coming year, 1909, and stated that these nominations need to be presented at the next meeting of the Section, to be held December 11, 1908.

There being no other business, Mr. W. D'A. Ryan, of the General Electric Company, was introduced, who addresed the meeting on "Recent Developments in Artificial Illumination." The paper was illustrated with a considerable number of lantern slide views. Discussion followed from Messrs. James Lyman, D. W. Roper, E. H. Freeman, P. Junkersfeld and J. R. Cravath.

The meeting adjourned about 10 p. m.

EXTRA MEETING, November 18, 1908.

An extra meeting of the Society (No. 644) was held in the Society rooms, Wednesday evening, November 18th.

In the absence from the city of President Loweth, the meeting was called to order at 8:30 p. m., with Past President Abbott in the Chair, and about forty-five members and guests present.

There was no business to transact, so the speaker for the evening, Mr. Carl Scholz, of the Rock Island Coal Co., was introduced, who addressed the meeting on "Coal Briquetting."

Besides some lantern slides to illustrate the paper, the author had on exhibition a number of briquets of coal, of various sizes, shapes and makes, and a blue print to show the arrangement of the machinery of a coal briquetting plant at Hartshorn, Okla.

Discussion followed from Messrs. W. R. Roberts, H. B. MacFarland, Geo. M. Mayer, A. Bement, J. K. Deering, H. A. Allen, R. H. Kuss, C. W. Naylor, Mr. Scholz and the Chairman.

The meeting adjourned about 10:10 p. m.

REGULAR MEETING, December 2, 1908.

A regular meeting of the Society (No. 645) was held Wednesday evening, December 2nd. The meeting was called to order at 8:25 p. m., with President Loweth in the Chair and about 65 members and guests present.

The minutes of the meetings of November 4th and 18th were read by the Secretary and approved. The Secretary reported from the Board of Direction that at its meeting held December 1st, the following were elected into membership:

	Grade.
Arthur R. Young, Chicago	Active
Neet C. McCanliss, Missoula, Mont.	Active
Alex. H. Bluel, Chicago	Junior
Ralph Budd, Cristobal, Panama	Active
James R. Scott, Chicago	Junior
Ray E. Pauley, Sioux City, Iowa	Active

Also that applications for membership had been received from:

Carl W. Boynton, Chicago.
Ralph G. Mansfield, Chicago.
Edwin A. Howes, Chicago.
Charles C. Chappelle, Chicago.
Frank E. King, Milwaukee.
Maj. Thomas H. Rees, U. S. Engineer, Chicago.
Frank H. Bernhard, Chicago.
David M. Craig, Chicago.

Announcement was also made that, in accordance with the By-laws, notices had been sent out to the membership concerning the nominations for officers of the Society for the coming year, and that petitions for nominations for sundry members for the officers of the Society had been received and presented to the Board of Direction at its meeting held December 1st.

The results of these petitions are as follows:

For President—
- Mr. Andrews Allen,
- Mr. J. W. Alvord,
- Mr. John Brunner,
- Mr. Wm. B. Storey, Jr.

For First Vice President—
- Mr. W. L. Breckenridge,
- Mr. John Brunner,
- Mr. Peter Junkersfeld.

For Second Vice President—
- Mr. John Brunner,
- Mr. O. P. Chamberlain.

For Third Vice President—
Prof. W. F. M. Goss, of Univ. of Ill.
Prof. W. K. Hatt, of Purdue.
Mr. E. H. Lee.

For Treasurer—
Mr. Albert Reichmann, to succeed himself.

For Trustee, to serve three years—
Mr. George M. Brill,
Mr. Ernest McCullough,
Mr. Wm. B. Storey, Jr.

The Secretary stated that as soon as the nominees are heard from the ballots will be prepared and sent out to the active membership of the Society.

There being no further business to bring before the Society, the Chairman introduced Mr. H. H. Evans, Engineer Secretary to the Local Transportation Committee of the Chicago City Council, who addressed the meeting on "Developments in Electrification of Railway Terminals." Discussion followed from Messrs. P. Junkersfeld, E. N. Lake and James Lyman, all members of the Society. The Chairman invited discussion by letter on this interesting and timely subject and said that an adjourned meeting for further discussion of this matter could be held if there was occasion for it.

The meeting adjourned at 10:30 p. m.

MINUTES OF THE ELECTRICAL SECTION, December 11, 1908.

A regular meeting (No. 37) of the Electrical Section, (being No. 646 of the Society) was held in the Assembly room, 1735 Monadnock Block, on Friday evening, December 11th, 1908.

The meeting was called to order about 8:25 p. m., with Mr. D. W. Roper as Chairman, and about 50 members and guests present.

The minutes of the meeting held November 3rd were read and approved.

In accordance with the rules governing the section, nominations by petitions for officers of the Section for 1909, to be voted at the next regular meeting January 8th, 1909, were presented in writing.

For Chairman, W. B. Jackson.
For Vice Chairman, P. B. Woodworth.
For Member for three years, W. L. Abbott.

The Secretary made the announcement of the next meeting of the Society, to be held Wednesday, December 16th, 1908, when Prof. Pence would be the speaker; also, that there would be a meeting of the Chicago Section, A. I. E. E., to be held Thursday evening, December 17th, 1908, at 8 o'clock p. m., in Fullerton Hall, Art Institute, on which occasion Prof. Chas. Steinmetz would address the meeting on "Light and Illumination"; also that the annual meeting of the Society, with a dinner, will be held Tuesday, January 5th, 1909, in the Club House of the Chicago Athletic Association.

There being no other business to bring before the meeting, Chairman D. W. Roper opened the discussion for the evening on the "Electrification of Railway Terminals," a paper by Mr. H. H. Evans, presented before the Society December 2, 1908. He was followed by Messrs. W. B. Storey, Jr., W. E. Symons, W. L. Abbott, Wm. B. Jackson, W. M. Camp and H. H. Evans.

The meeting was adjourned about 11 p. m.

EXTRA MEETING, December 16, 1908.

An extra meeting of the Society (No. 647) was held Wednesday evening, December 16, 1908. The meeting was called to order about 8:25 p. m., with President Loweth in the Chair and about 60 members and guests present.

There was no business to bring before the meeting so the Chairman in-

troduced Prof. Pence, M.W.S.E., of the University of Wisconsin, who presented his paper on "The Work of the Engineering Staff of the Wisconsin Tax and Rate Commissions." There were some lantern slide views shown to illustrate the paper.

Prof. Burgess, of Madison, Wisconsin, was then introduced, who spoke on some of the work connected with the above Commissions in the matter of gas and electric lighting.

Other discussions followed from Messrs. Wm. B. Jackson, G. T. Seely, C. K. Mohler, L. P. Breckinridge, A. Reichman, W. B. Storey, Jr., W. I. Symons, E. N. Layfield, P. Junkersfeld and President Loweth.

The meeting adjourned about 11 p. m.

J. H. WARDER
Secretary.

THE SMOKER.

October 29, 1908.

The Entertainment Committee arranged for a House Warming in the new quarters of the Society, Monadnock Block, which was in the form of a "Smoker," and was held Thursday evening, October 29th, 1908.

In response to letters of invitation from President Loweth, to all the Past Presidents and Charter members of the Society, most of the Past Presidents and early members of the Society were present in person or by letter. The Entertainment Committee provided some good instrumental music; also a very satisfactory lunch, which was served after the conclusion of the formal exercises of the evening, all of which were much appreciated.

President Loweth presided, and gave a brief account of the progress of events which resulted in securing the enlarged space, and in the development of the reconstruction and furnishing of the rooms now occupied. Through the efficient Building Committee and the professional services of Mr. Renwick, M.W.S.E., of Holabird & Roche, Architects, the results are satisfactory. There is a good assembly room, well lighted and ventilated, having a seating capacity for about 170; a cozy, quiet library room with bookcases and open stacks; a cheerful and attractive reading room opening into the library; spacious accommodations for the Secretary and his assistants; a committee room adjacent to the Assembly room, used also for the meetings of the Board of Direction, and a store room (or work room) where are stored sundry volumes of bound periodicals and the recent issues of our exchanges, the Addressograph, etc.

The cost of the improvements, including the lighting, ventilation, some furnishings, etc., amounting to about $6,500.00, was paid by the Society without going into debt, and with a working balance at the end of the year. A lease of this new space has been made with the agents of the building for ten years, but necessarily at an advance, with the increased space acquired.

The President then introduced his predecessor, Past President W. L. Abbott, who had been so active in forwarding the ideas embodied in the arrangement of the new quarters.

Mr. Abbott in his remarks called attention to the condition of the Engineering Profession forty years ago, just prior to the organization of the original "Civil Engineers' Club of the Northwest" and what it has become.

It was about a year ago that the Board of Direction considered the plan of enlarging the space for the use of the Society, and recommended to their successors, (the Board of Direction for 1908) that with a membership of nearly 1000, and a comfortable bank balance, it was eminently fitting that this foremost engineering society in the West, should have a better home, with a more commodious assembly room and accessories. This has been obtained, as you can all observe. But large membership with material prosperity does not constitute true greatness. If the Western Society of Engineers is to fully realize the opportunities to which it is heir, the well known and busy members must not shirk their obligations to the Society, and leave the writing of papers to the younger and less experienced; and the zeal of the officers of the Society must be rewarded by devotion on the part

of the membership. It is only by earnest effort on the part of all, that ours will become THE Society of Engineers of the West.

Mr. L. P. Morehouse, the first Secretary, and who filled that office for nineteen years after the original organization in 1869, followed Mr. Abbott with some delightfully humorous remarks relating to the early history of the Society, its small beginnings, and its gradual growth and development into its present substantial proportions.

Mr. Chanute, Past President, followed with a few remarks concerning the growth and standing of engineering since the beginning of this Society, and this was further enlarged upon by the remarks of Past President, Bion J. Arnold, who has had so much to do with the development of the application of electricity to transportation.

The venerable charter-member, Mr. A. Comstock, of Joliet, was present, but his remarks as to the organizing of the Civil Engineers' Club of the North West was in the form of a letter which was read by the Secretary, as follows:

"I will give you my recollection of the Organization of the Civil Engineers' Club of the North West. I can not give the exact date, but will suggest how it may be determined.

"I was engaged in making a survey near the Chicago and Alton R. R. bridge, crossing the Kankakee river in the village of Wilmington. This was one of the 'Post Patent Combination Bridges,' the tension members being of wrought iron and the compression members of cast iron. A party came down from Chicago to inspect this bridge which had just been erected. Of this party, I remember Mr. Booth, Mr. Draper, Col. R. B. Mason, Col. Post, Mr. Morehouse and I think Mr. L. A. Clark and Mr. Chesborough. There were a number of other persons whose names I do not recall.

"Mr. Draper came to me, and requested the loan of my instrument to be used in determining the deflection of the bridge under applied loads. This was granted him and the tests and inspection completed.

"I started on the evening train to return to my home in Joliet, when I was informed that it was contemplated to organize an Engineer's Club, and was invited to accompany them and participate in the meeting, which I did. I think the meeting was held on the train, as I do not remember going into Chicago, but I think I caught an outgoing train before reaching the city. I think the Club was fully organized and officers elected at this meeting, but it may have been at a later meeting in the city.

"A full account of the inspection of this bridge will doubtless be found in the daily papers of that date, and possibly mention may have been made of the Engineers' meeting also. I regret that my memory is so deficient in this matter, but if these lines may aid in clearing up any points in the early history of the Club, I shall be greatly pleased.

(Signed) "ADAM COMSTOCK."

Mr. L. E. Cooley gave some interesting and humorous reminiscences of when he was Secretary of the Society in 1888, following Mr. Morehouse, who had filled that position for the nineteen years previous; also of when he was President in 1890 and in 1891. It was during this two-years' term, that it was made a rule that a President should not immediately succeed himself. Mr. Cooley humorously supposed that he had been "a frightful example" that led the Society to pass such a rule. It was about this time that the Society had a membership which grew to nearly 400 about 1892, and the members would discuss and dream of the time when the Society might have, say, 600 members and be self-supporting.

It was a cause for regret that illness prevented the presence of Past Presidents, Gen. Wm. Sooy Smith, Capt. Robert W. Hunt and Mr. W. H. Finley, but Messrs. Artingstall, Randolph and Horton made responses when called upon, as did also that ever faithful and loyal member of the Society for the past thirty years, Mr. G. A. M. Liljencrantz.

Some of the letters received are here presented:

New York City, October 28, 1908.

Mr. C. F. Loweth, Chicago, Ill.

My Dear Sir: I have only just received your kind letter of the 21st inst., forwarded to me from Schenectady, and I beg to thank the Board of Direction of the Western Society of Engineers for the invitation to be present to-morrow evening, and make a "few remarks," on the occasion of the opening of new and more commodious rooms for the use of the Society.

This will certainly be a most interesting event and I regret very much that I cannot be present. It is more than gratifying to know of the growth of the Society, and with my best wishes for its continued success, I am,

Very truly yours,

(Signed) Alonzo W. Paige

(Charter Member.)

October 28, 1908.

Mr. C. F. Loweth, President W. S. E., Chicago, Ill.

Dear Sir: I am in receipt of your letter of the 21st instant, written in behalf and by the direction of the Board of Directors of the Western Society of Engineers, requesting my attendance at a "House Warming" in the new rooms which have just been fitted up for the use of the Society.

I regret very much that a prior engagement out of the city will prevent my being on hand to witness the contrast between the "New House" of the Society and the small office of Col. R. B. Mason—its first President—where it had its inception over thirty-nine years ago. Then it was a handful of ten, now a thousand. Of those still living who were members the first year, only six are on the roll to-day: L. P. Morehouse, Octave Chanute, Walter Katte, Alonzo W. Paige, A. Comstock and myself. Of these, our worthy "Past Secretary" and only "Honorary Member" L. P. Morehouse heads the list, with over nineteen years of faithful service in the interest of the Society, and to his efforts and those of the only ex-President of '69 living, Mr. Octave Chanute, the Society owes its existence.

When the question of who should write the first paper arose, it was decided that the members should be taken in alphabetical order, and the first one fell to my lot and was on "Railway Frogs." At that time the cast iron plated frog was the one in general use, one which required re-plating every three months under ordinary traffic. Under present conditions they would be useless.

As the finances of the Club were very small, the writers went to the expense of having these papers printed.

When we stop to consider the great advance made in all departments of railway work and management during the last thirty-nine years, one feels that he has not lived in vain, and that the future will show even more marvelous advances is assured.

It should be very gratifying to the officers and members of the Society that the increase in membership has been so large and that its finances are in such a healthy condition. That it may continue in its good work is the sincere wish of one of the 1869-ers.

Very truly yours,

(Signed) Jno. E. Blunt,

(Charter Member.)

Pomona, Cal., Oct. 26, 1908.

Mr. C. F. Loweth, Pres. W. S. E.

Dear Sir: Your so kind letter of the 21st inst., containing invitation for Society meeting the 29th, is to hand this a. m., and I reply by return mail. The distance is so great, this letter will scarcely reach you before the meeting.

Your list of members contains only 16 names of those who were mem

bers when I joined. Were I present with you all, as I shall be in spirit, in my eyes:

"There are more guests at table than the hosts invited:

The illuminated hall is thronged with quiet, inoffensive ghosts,

As silent as the pictures on the wall.

The stranger at my fireside cannot see the forms I see, nor hear the sounds I hear.

He but perceives what is; while with me, all that has been, is visible and clear."

You have now over 1,000 members, but in the "Seventies," it was a hard struggle for a handful of indomitable men to keep the Society alive. Time and again they were on the verge of despair, but they persevered and your condition to-day is the result. Do not forget them. Your quarters are far beyond anything to which they aspired, yet remember:

"We may build more splendid habitations,
Fill our rooms with paintings and with sculptures,
But we cannot buy with gold the old associations."

Members of the Western Society of Engineers have wrought their names in indelible letters by their works, and their fame will endure for ages.

It has been my privilege not only to witness the growth of our Society, but also of that great city of Chicago, for I was born there (Madison and Michigan Ave.)

Wishing one and all success, and that the Society may continue to grow and prosper. Believe me,

Sincerely your fellow member,

(Signed) AUGUSTINE W. WRIGHT,
Past President.

ST. DAVIDS, PA., Oct. 27, 1908.

Mr. C. F. Loweth, President, Western Society of Engineers, Chicago, Ill.

MY DEAR MR. LOWETH: Your kind favor of the 21st inst., in reference to the proposed "House Warming" on the 29th, is just to hand, and I hasten to reply so that it may reach you before the jollification becomes a "has been."

Words cannot express the depth of my regret that I cannot be with you to enjoy the meeting of so many of my old comrades, as well as many members whom it has not been my pleasure to meet.

The great success of the Society during the past twenty years or more, since I first took active part in the management with others now gray capped, and some who passed beyond this earthly life, is a most satisfactory evidence to me that we struck out in the right direction when we decided to "paddle our own canoe" without the help or hindrance of "Affiliated Societies," and to hold the management (Board of Direction) responsible, instead of constituting the entire membership as a legislative body. Some of the younger members may not fully understand the meaning of the above statement, but I trust many of the "Old Guard" will be there to explain and give echo to the sentiment. It is my hope that they will give reasons for the change of policy inaugurated, to the end that the newer blood may be so inspired with the wisdom of the plan of procedure that they will not permit it to lapse, but carry on the great work in a conservative and thoughtful manner, to the great benefit of, not only the engineering profession, but all mankind.

It was evidently no mistake to assume that the management would be thoroughly competent if the responsibility for good government was placed upon them, as has been shown by the ability with which the affairs of the Society have been administered up to the present time, and as I firmly believe the good work will continue.

Permit me to offer a toast to the Pioneers, the Rescuers and the Conservators of the Western Society of Engineers.

Thanking you and your Board of Direction for the opportunity offered

me to join in the good time, and wishing you all a most enjoyable evening and the Society every success, I am,

Yours very truly,
(Signed) HIERO B. HERR,
Past President.

NEW YORK, N. Y., October 26, 1908.

C. F. Loweth, Esq., President, Western Society of Engineers, Chicago, Ill.

MY DEAR MR. LOWETH: I am in receipt of your kind invitation of October 21st, requesting me to be present at the house warming of the Western Society of Engineers on the 29th instant, and regret exceedingly that I am so unduly pressed by many things which require attention in the East, that it will be impossible for me to be with you on that occasion, and address the Society as you suggest.

My heart has always been with the Western Society of Engineers, and I have watched its growth with pride and pleasure. I feel that some of my warmest friends are members of the Society, and that nowhere would I have received a heartier welcome. As a Past President of the Society, I am and always will be interested in its affairs, and will always be pleased to lend my best aid to its future advancement and continued success.

Yours very truly,
(Signed) JOHN F. WALLACE,
Past President.

NEW YORK, October 24, 1908.

Mr. C. F. Loweth, President, Western Society of Engineers, 1735 Monadnock Block, Chicago, Ill.

MY DEAR SIR: I have your letter of the 21st, with the courteous invitation from the Board of Direction to take part in the "House Warming" on the 29th inst.

It would give me the greatest pleasure to be present on this auspicious occasion and to pay my compliments to the management of recent years on the splendid record which they have made in building up a great society with such an excellent financial showing, and to congratulate the Society on the new quarters obtained on such satisfactory terms.

When I came to Chicago in 1892, the Society was in a deplorable condition with no available library, no creditable quarters, no funds, a small membership with little prospect of increase and of little influence and usefulness. Its principal asset, but a most valuable one, was a remarkably efficient Board of Direction which included as particularly active members, Capt. Robert W. Hunt, who is still among us with undiminished zeal and perpetual youth, ready for any service to promote the best interests of the engineering profession, and Mr. Geo. S. Morison, since cut down in the height of his career, whom we may all agree was the greatest engineer of his time, in this or any country. This Board, adopting somewhat heroic measures, reorganized the Society, gave it a home adequate for its needs at that time, put its small library in order and provided for its enlargement, and adopted a pay-as-you-go policy which has never been abandoned. I was cognizant of this work at the time to some extent, although not then a member of the Society, but appreciated its excellence more fully a few years later when honored by the Society by election to membership on its Board. At that time the Society, still small in numbers and influence as compared with the present magnificent and powerful organization, was on a solid foundation and was developing its facilities as fast as prudence permitted, with a steady increase in membership.

Perhaps the most important step ever taken by the Society, was the decision to publish its own proceedings. To some of us it seemed unwise to incur this responsibility, but within a short time the success of the JOURNAL was assured and the growth of the Society greatly promoted thereby.

It was a happy inspiration, it seems to me, to omit the word "Civil" from

the name of the Society. The value of the word to distinguish between the engineering of peace and that of war has long since disappeared, and it has come to have a restricted meaning as referring to those branches of engineering not yet specialized. I believe the most general title has a real value in encouraging a broader spirit and tending to gather into one organization as a unit professional engineers of all branches; when thus united the influence of the profession and its capacity for public service is greatly enhanced. The organization of an Electrical Engineering Section was an important step in this direction and the Society is to be congratulated on having thus taken an advanced position. As a result of the broad policy steadily pursued by the Society the papers presented to it, cover a wider range of engineering work than those of any other engineering organization in the United States.

Every great development in the work of the Society has followed frank discussion, and has been free from subsequent dissension in a manner characteristic of the West and particularly of Chicago. The continuance of this spirit of frankness and loyalty and persistence in a broad policy in professional matters and in prudent financial management will make secure an honorable and useful future.

Yours very truly,
(Signed) Alfred Noble,
Past President.

The meeting adjourned about 11:30 p. m., and all expressed themselves as having greatly enjoyed a very pleasant social meeting.

BOOK REVIEWS

Water Power Engineering: By Daniel W. Mead, Mem. Am. Soc. C. E., M.W.S.E., Professor of Hydraulic and Sanitary Engineering, University of Wisconsin. 6¾ by 9¼ ins.; 787 pages, 413 illustrations, many tables and diagrams. Cloth bound. Price $6.00. McGraw Publishing Co., New York, 1908.

The development of electricity and its transmission, during the past ten years, has given new life to the water powers. Although installations aggregating many thousand horse powers were made at an early time, the majority of these plants were built for the use of industry more or less fixed in extent, and it has been only comparatively recently that installations have been demanded, capable of developing the streams to their maximum economical limit. The design of these larger plants has made felt the want of a more exact knowledge than has heretofore existed, relating particularly to the amount of power and its best use. The early books, treating more particularly of the structures involved, were supplemented some half dozen years ago by Frizell's excellent book on low head powers, and now Professor Mead comes forward with a distinct advance along this line. His book embodies the best resume of power investigation that has thus far appeared.

Following short chapters on the history of the art, and power and its losses, fundamental hydraulics is reviewed, particularly as it affects the power problem. This chapter contains some ingenious diagrams for the solution of Chezy's formula, and the complicated equation of Kutter. It also reviews, in diagramatic form, the weir coefficients of Bazin, and those deduced by Rafter and Williams in the Cornell experiments. The problem of back water is more briefly considered than the importance of the subject warrants. This deficiency should be remedied in future editions. The method outlined of observing actual existing coefficients for use in back water computations is worthy of especial notice.

In the eight chapters following, relating to the amount of power, lies the strength of the book. Perhaps no water power engineer has made better use of the valuable data recently collected by the U. S. Geological Survey than has Professor Mead, and the graphical means outlined for the comparison of

hydrographs is believed to be the best method of approximating available flow that we have today.

The chapter upon head is excellent, and, while the general method suggested is in use by a number of engineers, the application of a graphical diagram, showing at once the relations between flow head and size of installation, is new, ingenious, and clear. This is a matter most vitally affecting low head powers, and is usually given insufficient attention in water power studies.

The chapters on rainfall and its disposal reviews the best of the published data, much of it reduced to convenient diagrams. In the chapters upon stream flow and measurement an admitted free use is made of the Water Supply Papers.

Chapters twelve to twenty-two are devoted to the water wheel, which is approached from the standpoint of the user rather than the designer. A chapter on the classification and the development of the modern turbine is followed by one on details. Both chapters are enlivened by many excellent cuts. Chapter fifteen, hydraulics of the turbine, reduces the relation of discharge, head, power, diameter, and speed to convenient formulae, and contains the tabulated wheel constants of nearly thirty American manufacturers, evidently compiled at no small labor. Then follows turbine testing, an excellent chapter on the selection of the turbine, the load curve, a mathematical discussion of speed regulation, the governor, wheel settings, and appurtenances of the water power plant.

The remainder of the book is devoted to descriptions of a few typical plants, a quite brief discussion of dams, well covered in other publications, a chapter on pondage, and a chapter on power cost containing some valuable tabular compilations.

An appendix of eighty pages contains some mathematical discussions omitted from the text, and full tabular data of many turbine tests. Then follows last, but not least, a good index.

The work is presented in text book style, with numbered articles and formulae; and numerous headings in bold type, make it alike convenient to the student and, for reference, to the engineer. Some of the discussions, however, would be clarified by more frequent paragraphing. The type is good, and the illustrations and diagrams, of which there are some four hundred, are nearly all well drawn.

Each of the twenty-eight chapters is followed by a most complete bibliography relating to the subject treated, covering, in all, upward of a thousand references to curent literature.

C. B. B.

ENGINEERING WORK IN TOWNS AND CITIES: By Ernest McCullough. Myron C. Clark Publishing Co., Chicago and New York. 510 pages; $5\frac{1}{2}$ by 8 in. Cloth. Second edition 1908. Price \$3.00 net.

This book is written for the use of Officials, Boards of Improvements, and Engineers in towns and cities of 20,000 inhabitants or less. There are 14 chapters of text, a table of contents and an index of 1420 references.

The first chapter is on "The City Engineer and His Duties," followed by seven chapters on municipal work under the following headings: Roads and Streets; Walks, Curbs and Gutters; Street Pavements; Sanitation; Drainage and Sewerage; Water Supply and Concrete Work. Chapter nine, takes up Contracts and Specifications; and chapter ten, Miscellaneous Data, such as Lighting, Building Regulations, Franchises, etc. The last four chapters cover Office Systems, City Engineers' Records, Field Work and Engineering Data.

In the first chapter the author presents an ordinance defining the duties of the engineer, which is short and leaves no indefinite understanding. Towns which have reached a stage in their development where they require an engineer will find this a model ordinance. Ordinances are also given in the chapter on Sanitation regulating plumbing work; in the chapter on

Sewerage, regulating sewer connections; and in the chapter on Roads and Streets, covering the establishment of grades.

The chapter on Contracts and Specifications treats these subjects in a general way and some good advice is given to town officials relative to the essentials of a contract. Model specifications covering each class of work are given in the chapter relating to that subject.

The last four chapters of the book are of especial interest to the city engineer and contain a great deal of valuable information on office systems and keeping up records. followed by tables and diagrams required for every day use.

The author has quoted liberally from the best writers on the various subjects treated, but much of the matter is the accumulation of his own experience in this kind of work. There are a great many drawings and tables interspersed through the text. The author has endeavored to get out a work in which every chapter will be an interest to both the technical and non-technical reader, and in this he has succeeded very well. The type work and binding are excellent. G. H. H.

The Principles and Practice of Surveying: Volume II. Higher Surveying. By Charles B. Breed, Assistant Professor of Civil Engineering; and George T. Hosmer, Assistant Professor of Civil Engineering, Massachusetts Institute of Technology. New York, John Wiley and Sons, 1908. Cloth, 6 by 9-in. 432pp, Price $2.50.

The subjects included in this volume are treated according to the same general plan followed in the first volume of this work: the apparent intention being to make the book a manual of field practice, equally useful to the student for class room work, and to the practical surveyor. As stated in the preface, "It is not the intention in any sense to present a treatise on Geodesy". In this respect the book is not a treatise on "Higher Surveying".

The volume is divided into four parts as follows: "The Control of the Survey", "Filling in Topographic Details", "Hydrographic Surveying and Stream Gauging", and "Constructing and Finishing Maps".

Part I contains chapters on triangulation, astronomical observations and leveling. Part II includes a very well written chapter on the stadia, the discussion of which was so noticeably brief in the first volume. In addition are chapters on the plane table, on the photographic method, and on "The Relation of Geology and Topography". The author of the latter chapter emphasizes the advantage to be derived from a knowledge of geology by the topographer. The divisions of the book devoted to hydrographic surveying and to mapping contain little that is new in the discussions of these subjects. There are seventeen tables.

Every part of the book shows great care in its preparation. The arrangement is good and while the two volumes appear large, the size seems to be justified when the scope and purpose of the work are considered. There is reason to believe that the completed work will take a high place in the literature on this subject. M. B. W.

Steam Power Plant Engineering. By G. F. Gebhardt, Professor of Mechanical Engineering, Armour Institute of Technology. 6 by 9 ins.; 816 pages, including index; 461 figures and diagrams. Cloth, price $6.00 net. New York, John Wiley & Sons; 1908.

After looking over the twenty-one well-arranged chapters, and six appendices, contained in the book, the reader feels that the author deserves to be congratulated on the thorough and simple manner in which the numerous subjects are classified and considered. As the title would imply, the book is devoted to all classes of power plants and central station machinery. It contains a fund of exceedingly interesting descriptive matter and data pertaining to the mechanical equipment usually found in modern steam-electric plants.

The opening chapter is confined to a general description of elementary steam poweer plants, and gives the various common average heat losses found in such installations. The next chapter deals with the composition and characteristics of solid and liquid fuels, and their combustion. Some space is also given to the different methods of firing boilers with fuel oil, with a number of illustrations showing the various types of oil burners and furnaces. In the succeeding chapters the following subjects are referred to: Boilers, smoke prevention, furnaces, stokers, superheated steam aand superheaters, coal and ash-handling apparatus, chimneys, mechanical draft, steam engines, steam turbines, condensers, feed water purifiers and heaters, pumps, separators, traps and drains, piping and pipe-fitting, lubricants and lubrication, finance and economics, testing and measuring instruments. There is also a chapter on typical specifications; Fisk St. Station of the Commonwealth Edison Company and a description of the New York Central & Hudson River railroad company's West Albany station.

The chapters applying to boilers, superheated steam, and steam turbines are especially worthy of note, as they contain among other things, numerous curves taken from recent tests by different authorities. The figures and diagrams throughout the book are exceptionally clear and simple, as is also the printing.

In his preface the author draws attention to the fact that the book is the outcome of a series of lectures, and that it was primarily intended as a text for engineering students. It appears especially well adapted to that use. While the different subjects are treated in an elementary way, there is enough every-day power plant information to make the book a valuable adjunct to the libraries of practicing aand operating engineers.

On page 598, Chapter XV, various rules for determination of safety valve areas are given, one of which applies to the regulation of the United States Supervising Inspectors of steam vessels. This rule was outlawed in January, 1904, and the superseding regulation takes into consideration the amount of steam actually generated to determine the valve area, instead of basing it on the amount of grate surface.

Included in the appendices are the A. S. M. E. rules governing the testing of boilers and engines, also steam and miscellaneous conversion tables. At the termination of paragraphs, where, for lack of space additional matter could not be given, there is appended reference to different authorities and technical publications.

In general, the book is very creditably written, and as a ready reference it should be given serious consideration by engineers and others. F. T. C.

CONCRETE SYSTEM. By Frank B. Gilbreth. New York. Engineering News Pub. Co. 1908. Flexible leather, 11½ in. by 8 in., oblong; pp. 182; 10 folding plates, and over 200 half-tone illustrations. Price $5.00

This book, by the author of "Field System", bears a close analogy to the earlier work, but differs from it in that this relates to concrete building work specifically.

As in the earlier work, the book was written primarily for the benefit of the building organization of the author, but there is so much of value in it that it has been published for the benefit of the engineering profession.

The book is not an analytical treatise of concrete, nor of the necessary calculations for designing beams, slabs, columns, etc. of this material, but is mostly a series of rules for the use of Superintendents, Foremen and Workmen, the result of extended experience in concrete construction, the following of which rules will assist in securing the best work and at the least expense to the contractor. These rules are accompanied in many cases with illustrations to assist in making them clear, and in a general way the compilation of these rules seems admissible.

As a suitable supplement to the main part of the work, there is introduced the "The Standard Methods of Conducting Cement Tests", as proposed by the American Society of Civil Engineers, and the "Standard Specifica-

tions for Cement", as prepared by the American Society for Testing Materials. It is well to have these two important matters, as proposed by such eminent authorities, introduced into the book as being pertinent to the subject.

Other subjects treated are the "Finishing" (of surfaces) and the making of "Cast Stone", which is often employed to advantage in connection with stone or brick masonry as well as monolithic concrete construction.

An interesting chapter relates to the manufacture and driving of concrete piles for foundations. When these can be used satisfactorily there can be nothing better, though it is questionable if they could take the place of the concrete piers as used in Chicago for heavy buildings, and which extend up from bed rock, one hundred feet if necessary, through the soft clay underlying this city.

The value of concrete to resist the action of the heat of a fire is of interest, whether the structure contains reinforcing metal or otherwise. Tests have been made to shed some light on this subject. Certain tests have been made and reported in this book with many illustrations, which are a valuable contribution to our knowledge of this matter.

The latter part of this book contains a very full account of that notable reinforced concrete business block built for the McGraw Publishing Company, with Mr. W. H. Burr, M. A. S. C. E., as Consulting Engineer. This is illustrated with ten folding plates, besides many half-tone engravings, showing how the work was managed, which was admirable from all accounts and redounds greatly to the credit of the contractor and his organization.

We hear frequently of "team work", whether on the football field or in construction work, and this book is an example of how a contractor can organize and discipline his force of assistants and workmen to do most effective "team work", to obtain satisfactory and economical results. W.

Alloys, (Non-Ferrous). By A. Humboldt Sexton, F. I. C., F. C. S., etc. The Scientific Publishing Company, Manchester, England. Cloth, 5¾ in. by 8¾ in., pp. 284 and index; 137 illustrations and diagrams. Price 7s. 6d. net.

This book contains a great deal of valuable information pertaining to the alloys used mostly in modern shop work, consisting of copper, zinc, tin, lead, etc. in varying proportions and usually known as brass, bronze, white metal, etc.

There is a good introduction explaining the nature of alloys and solutions of metals in other metals, which solutions may contain many varying ratios of the constituents; also explaining how these mixtures are to be studied by chemical analysis and by the aid of the microscope; also a study of their physical characteristics, as well as the phenomena of fusion and solidification.

There is a chapter on the metals used in the preparation of alloys, with a classification of the best known alloys and the most important of these—the brasses, the bronzes, the white alloys, the fusible alloys, those of the precious metals, etc.—are elaborated upon in some eight or nine chapters.

The last chapter, the fifteenth, relates to the preparation of alloys and contains some very interesting matter pertaining to the melting and mixing of the constituents, with illustrations of various forms of furnaces and with data as to cost of fuel, whether solid, liquid or gaseous, and their relative merits.

The microstructure of metals, a comparatively recent method of studying metals and their alloys by the aid of the microscope, is referred to frequently by the author with views, photographic illustrations, of various alloys.

Altogether the work is an interesting and valuable one. W.

Surveyor's Hand Book. By T. U. Taylor, Professor of Civil Engineering in the University of Texas, etc., etc.; 310 pages. 4½ by 6¾ ins. 116

figs. Tables of logs, trigonometric functions, etc. Flexible leather binding, pocket book form. $3.00. Published by the Myron C. Clark Publishing Company, Chicago and New York.

This book is remarkable for its conciseness. Brevity is oftentimes used when a thing is stated in so incomplete form that statements are apparently brief. In this book, however, brevity is attained without sacrificing completeness.

The book is a true pocket book for surveyors and is at the same time so complete that it can well be used as a text book in nine tenths of the engineering schools. The present tendency in these days of overcrowded engineering courses is towards verbosity in treatises on surveying and a student is carried by erratic leaps through a too complete text book, getting only a smattering in the school; it being supposed he will read up, as indeed he must, after leaving school.

This book is concise enough to be used as a text without skipping good parts and at the same time can be afterwards used in the field for ready reference. The chapters in their order are: I. Chain Surveying. II. Compass Surveying. III. Transit Surveying. IV. Calculation of Areas. V. Division of Land. VI. Leveling. VII. Topographic Surveying. VIII. Railroad Surveying. IX. Earthwork. X. City Surveying. XI. Plotting and Lettering. XII. Government Surveying. XIII. Trigonometric Formulas. XIV. Tables. McC.

Electrical Illuminating Engineering. By W. E. Barrows, Jr., Assistant Professor, Electrical Engineering, Armour Institute of Technology. The McGraw Publishing Company, New York. 1908. Cloth; 5½ by 8½ in., 216 pages, illustrated. Price, $2.00 net.

This book is stated in the preface by its author to have had its origin in a set of notes compiled for use in his classes. As there was no thought of publishing the material at the time it was compiled, no record was made of the sources of information. This is unfortunate because in many cases the subjects treated are necessarily dealt with so briefly that the student would find it an advantage to have a reference to the original sources of information, where he might study the various points more thoroughly, if so inclined.

As is stated by the author, the size of the book necessarily prohibits descriptive detail. The first chapter, on "Light and Color," takes up the questions of reflection coefficients of different surfaces, intrinsic brilliancies of various light sources, foot-candles required for satisfactory illumination, and the spectrum of various light sources. The chapter on "Units of Illumination and Photometry" is a combined summary of definitions of units and brief descriptions of various kinds of photometers. The former are timely and in convenient reference form. It is doubtful whether the latter are sufficiently complete to be plain to the student going over this subject for the first time, but they at least indicate the general types available and open the way for further study. One chapter is given to spherical photometry and integrating photometers. In this is taken up the use of the Rousseau diagram for the calculation of mean spherical candle-power. The recent method suggested by Dr. Kennelly is also given considerable space. As an indication of how rapidly improvements in illuminating engineering methods are being made, it is interesting to note that both the Rousseau and the Kennelly methods have been recently displaced in engineering offices where time is an object by the use of the flux polar diagram; this development doubtless having taken place since this manuscript left the author's hands. Part of this chapter is also given to spherical photometers of the Matthews and hollow-sphere types. The chapter on "Standards of Illuminating Power" takes up briefly the various standards which have found favor from time to time. A long chapter is given to "Incandescent Lamps," dealing with the characteristics of various types as to life, candle-power

and distribution of light. Arc lamps, flaming arc lamps and vapor lamps are also dealt with in similar chapters. A short chapter on "Shades and Reflectors" gives some of the characteristic distributions obtainable with some of the commoner types of glassware. A long chapter is given to "Illumination Calculations," the latter part being of considerably more theoretical than practical interest.

If, as is indicated in the preface, the book is intended as a basis for a short course in illuminating engineering, one cannot help wonder what must be the state of mind of the student who must attempt to cover so much ground as that covered in this book in a short time in such a hasty manner as it is there touched upon. On the other hand, if it is to be used as a series of suggestions for the instructor, who elaborates the various points in lectures as he goes along, it should be of considerable value, in an extended course. J. R. C.

Public Water Supplies. Requirements, Resources, and the Construction of Works. By Professor F. E. Turneaure and Prof. H. L. Russell, of the University of Wisconsin, with a chapter on Pumping Machinery, by Prof. D. W. Mead, University of Wisconsin, Madison, Wis. Second edition, revised and enlarged. Cloth, 6 by 9 inches; pp. 808 including index; 231 illustrations, many tables and diagrams. Price $5.00. John Wiley & Sons, New York, 1908.

This is a second edition of a book that was brought out in 1901, which at that time was the most notable work on this braanch of engineering.

The arrangement of the various phases of this interesting subject seems logical, as Chapter I, Introduction, gives a historical sketch of water works in general, and shows the value and importance of a public supply of water. Then follows Part I, Requirements and Resources, subdivided into A, Quantity of Water Required—Sources of Supply; B, Quality of Water Supplies. Part II takes in the Construction of Water Works, with Chapter XI, Water-works Construction in General, and Chapter XII on Hydraulics.

These are followed by several chapters under "A"—Works for the Collection of Water; under "B"—Works for the Purification of Water, and under "C"—Works for the Distribution of Water. The general treatment of this subject of Public Water Supplies is broad and comprehensive. One excellent feature of the book is an appendix to almost every one of the twenty-nine chapters it contains, which under the caption "Literature" gives a list of books and articles in technical papers, etc., relating to the subject of that chapter. These bibliographical notes are of great service to anyone who wishes to read up further on subjects connected with water-works.

Altogether the work is a very comprehensive one and of great value to those interested in water-works. W.

Electric Motors, Their Insulation, Control, Operation, and Maintenance. By Norman G. Meade. Cloth, 5 by 7¼ ins., 159 pages, many illustrations in the text. Price $1.00. McGraw Pub. Co., New York. 1908.

The author in his introduction states that his object has been "to explain the phenomena of electric motors, describe the leading types of motors and appliances, give suggestions in a practical manner for their installation, care, and management, for the use of practical men."

In Chapter I the author defines briefly the meaning of the term "motor" and states briefly the electrical and magnetic actions taking place. The effect of armature reaction upon commutation in direct current motors is discussed, with the aid of suitable diagrams. The effect produced in the short circuited coil in an armature by the distortion of the field flux and shifting of the brushes is very briefly mentioned, and a very brief description of the action in the induction motor is given, with some of the principal characteristics enumerated.

A chapter is devoted to a classification of the different types of direct current and alternating current motors. The different types in general use,

together with the important characteristics and peculiarities of each type are described. The author emphasizes the fact that certain types are especially applicable to certain classes of work. A short space in the chapter is devoted to the description of the electric and magnetic phenomena in "interpole" and various types of motors designed for wide speed regulation. A description is also given of the principal types of induction, repulsion, and synchronous motors.

Another chapter is devoted to the description of control and starting devices. The elementary principles which determine the selection of certain types of control apparatus for particular services are discussed, and the text is illustrated by cuts of commercial rheostats and starting devices and diagrams of connections of the more common forms of apparatus. The author perhaps has made a mistake in not explaining in more complete detail the diagrams, as in some cases the paths of the current could not be readily traced by one not familiar with the subject. A brief discussion is given of the various combinations of motor-generator sets and their application to commercial service.

The author emphasizese the fact that careful consideration should be given to the installation and suitable mounting and connecting of motors, as the successful operation and efficiency of an electric plant may be seriously impaired by inefficient work in this respect. He describes the details of the mounting and wiring, omitting, however, any reference to the calculations necessary to the proper selection and installation of motors.

Under the heading "Operating Hints" instructions are given for the testing of new motor installations. Some of the symptoms of the more serious motor troubles and the methods of testing for the same are described. Instructions are given for the maintenance of motors and auxiliary apparatus. The last chapter of the book is devoted to the description of methods of repairing direct current armatures. No space has been devoted to the description of repairs on alternating current apparatus or their auxiliaries. The author emphasizes the fact that the economical operation of the repair shop and its ability to quickly execute the necessary repairs is a subject of importance to every industrial plant using electrical power. He describes the requirements of an average sized shop, and goes into some detail in the description of repairs to commutators, methods of winding direct current armatures, etc. The last few pages of the book are devoted to various tables for use in connection with elementary electrical calculations. In these tables some of the principal formulas are absent, and the symbols in some of the others are not clearly defined.

In that portion of the book dealing with the general types of motors and their applications the author has described most of the important ones. However, he has not mentioned railway installations, which are among the most important of the applications of motor power. This is to be regretted, in view of the fact that a large part of all electric power is used in railway service. In the space devoted to control apparatus the different types of rheostats and controllers are described completely enough for a general understanding of their application to special services.

The book in general enumerates most of the important elementary considerations, although nowhere has the author gone into great detail. The book is clearly elementary. It contains nothing new to the man of wide experience with motors and similar apparatus, but consists simply of a collection of the basic principles involved in the application, maintenance, and repairs of electric motors and auxiliary apparatus.

E. I. S.

SMOLEY'S TABLES, PARALLEL TABLES OF LOGARITHMS AND SQUARES, ANGLES AND LOGARITHMIC FUNCTIONS, corresponding to given bevels, together with a complete set of FIVE-DECIMAL LOGARITHMIC TRIGONOMETRIC TABLES. By Constantine Smoley. Fifth edition, revised. Flexible morocco, 4¾ by 7 inches, 448 pp. The Engineering News Publishing Co., New York. 1908. Price $3.50.

This is a set of tables for the use of engineers and architects and is particularly applicable, at least in some parts, to the bridge and steel structural designer and draughtsman.

The first portion of the book and occupying some 300 pages, consists of a series of lengths of feet, inches and fractions, beginning at 1-32 inch and increasing by a constant difference of the same quantity through inches and feet up to fifty feet. In parallel columns with these lengths, will be found their logarithms and squares. This table has been extended since the first edition with variations by 1-16 inch, from fifty feet up to one hundred feet, and with the parallel columns of squares and logarithms.

There are many uses to which such tables can be applied, particularly in the solution of triangles, the determination of dimensions of unknown sides, etc. In the Engineering News of December 25, 1902, there is an article by Mr. T. D. Davis on, "Some Convenient Methods by Their Use."

Following these tables are fourteen pages of tables of angles and logarithmic functions, corresponding to bevels and slopes, given to a base of twelve inches. These bevels vary by 1-32 inch from 1-32 to twelve inches and the logarithmic functions consist of the Sine, Cosec., Tang., Cotang., Cosine., and Sec. The tables also includes the value of the angle of the bevel, as measured in degrees, minutes and seconds.

Another table, also of value to the bridge draughtsman, is a multiplication table for rivet spacing. The base of this is the pitch of the spacing and is from 1⅛ inches to 6 inches, varying by eighths. The multiplier is the regular series of numbers from unity to thirty. The product is given in feet, inches and fractions.

Another table is that of Decimal Equivalents, of all linear distances less than 12 inches, varying by 1-32 in.; as decimals of a foot. Another extensive table is that of logarithms of numbers up to 10000, to five places of decimals. This is followed by a table of logarithms, to five places, of trigonometrical function.

In conclusion there is a table of natural trigonometrical functions from zero to 45 degrees, varying by 10 minutes.

The paper and the typography is excellent and the book would stand a great deal of usage on the desk or draghting table. **W.**

Audels' Gas Engine Manual. Theo. Audel & Co., Publishers, New York 1908. Cloth, 5¾ by 8½ ins. XXIV+469 pages, including index and 156 illustrations. Price $2.00.

As may be inferred from the title, this book contains much that is instructive and useful for one who desires to know about the gas engine. It contains, in fact, too much information on too many different subjects to be of real value to the person who is already well versed in gas engines, their theory and operation.

It is difficult for one to determine what is really new in the book. When one looks for important data on any one of the types of gas engines described, he is unable to find it. Thirty pages are devoted to indicator cycles, and indicator diagrams and several diagrams are given which may have been taken from actual engines, but there is no diagram heading, "Taken from a Three-Cylinder Westinghouse Vertical Engine"; "Taken from a 60 H. P. Otto Horizontal Engine", or "Taken from a Tandem Burger Engine".

It is of value to know the best and most effectual way of silencing the exhaust of a large gas engine, but so far as one may infer from the test, he has only to say "Be Silent" and there will be silence. A good manual should give as complete a description of the silencer as of the governor. The same criticism may be made as to the weights of various types and makes of engines.

The cuts and illustrations are well gotten up and bring out the objective points most positively. To be sure, there are cuts of some engines no longer built and cuts of some of our best types are omitted.

The recent development of Gas Producers is of such great importance that a chapter of only eighteen pages seems inadequate for the subject.

The book is, upon the whole, worth looking over, but is too superficial to be of real value in a library. H. B. M.

Elementary Dynamics. A Brief Course in; for students of Engineering. By Ervin S. Ferry, Professor of Physics, Purdue University, Lafayette, Ind. The Macmillan Company, New York. 1908. Cloth, 6 by 9 ins., pp. 182, including index and tables, with 121 figures through the text. Price $1.25 net.

This book gives a brief and well arranged course in elementary dynamics. It is intended primarily for students in engineering, and to this the selection of illustrations and examples bears evidence, but these are so carefully chosen with a view to their broad and present day interest, that the book is likely to be found of general service in college physics.

Following a chapter on fundamental notions are two chapters on statics and seven on kinetics. Especial attention may be directed to the chapter on the composition and resolution of forces and to that on the motion of a body under the action of a torque. A. W. M.

Fowler's Mechanical Engineer's Pocket Book, 1909. By Wm. H. Fowler, Mem. Inst. Mech. Engs. 4 by 6 inches, 609 pp., many tables and illustrations. Leatherette binding with gilt edges. Price 2s. 6d. net. The Scientific Publishing Co., Manchester, Eng.

This is the eleventh annual edition and contains the matter of previous editions with additions to bring it up to date.

The book has that objectionable feature (in our eyes), so common in this class of English publications, of containing a great deal of advertising matter, but when the publshers explain that it is this feature which enables them to put forth so valuable a book, well printed, and bound, at a cost to our readers, in the United States, of perhaps about seventy-five cents (2s. 9d.), surely we can "skip the ads.", if they are not interesting

This work follows the lines usual to such publications, with tables of measurements, weights, conversion factors, mensuration, areas of circles, tables of squares, etc., logarithms, weights of metals in sheets, bars etc., surface speeds of rotating bodies, etc.

Then comes a section pertaining to steam boilers and fittings, with rules, formulae and tables. This is followed by fuels and combustion, with data on thermic values and composition of coals, gaseous fuels, etc., and includes the subject of chimneys, draft, etc. Considerable space is given to steam engines, turbines, locomotives, valves and valve gears, etc. Another section takes up the subject of gas engines and is followed by one on the gases for such motors.

Hydraulics, pumps, gearing, lubrication, hoisting, and lifting machinery, metaulurgy of metals and alloys and other subjects of interest to the mechanical engineer, all receive some attention in this handy little volume. W.

A Text Book on Roads and Pavements. By Frederick P. Spalding, Professor of Civil Engineering, University of Missouri. John Wiley & Sons, New York. 1908. 3rd edition. Revised and enlarged, 5 by 7 ins., 348 pp, 51 figs. Several tables. Price $2.00.

The author says in the preface that the methods employed in the construction and maintainance of highways have changed so greatly since the first publication of the book that this edition is a practically rewritten book. In it he has briefly represented the most recent practice in highway work.

There are eleven chapters taking up each of the materials most used in road and street improvement and the last chapter deals entirely with city streets. The work is very well done, but after all it is just what the author has named it "A Text Book" and the needs of the student have been

considered first. It has no index and the table of contents hardly supplies the need. If this book were supplied with a complete index it would be a very good book for the library of the civil engineer. It is really up to date and every man concerned in the construction and maintainance of roads and streets will find something in it of value. E. M.

Fowler's Mechanic's and Machinist's Pocket Book and Diary, 1909. By. Wm. A. Fowler, M. E. The Scientific Publishing Co., Mancheseter, England. 4 by 6 inches. 446 pp. in boards. Price 6d net.

This book contains "A Synopsis of Practical Rules for Fitters, Turners, Millwrights, Erectors, Pattern Makers, Foundrymen, Draughtsmen, Apprentices, Students, Etc.

"Although the book is designed primarily for the workman, its pages contain many useful notes and hints which Managers, Foremen and Draughtsmen will probably find occasionally of service."

It is interesting to note that the compiler, Mr. Fowler, has borrowed material from those excellent papers the "American Machinist" and the "American Machinery", as well as from the "Mechanical Engineer", of Manchester. Theere is much in the book that would have been highly appreciated and made use of, by the reviewer, had it been available in his "apprentice days."

There is an index, which, howeved, is somewhat marred by the printing of advertisements on alternate pages. Beginning with the usual signs and symbols, tables of squares, cubes, roots, areas and circumference of circles, weights and measures and metrical equivalents, weight of metal in bars, balls, etc., there follows a section devoted to mensuration, geometry and trigonometry. Next comes a section on "Machine Construction" with a description of materials employed, various alloys, etc., their proportions and strength. This is followed by "Machine Tool Designs", with many illustrations and tables that are interesting and valuable. The succeeding chapter gives "Proportions of Machine Tool Parts", illustrated and tabulated.

"Metal Cutting Tools", a subject which has been under revision and discussion of late years, is next taken up, with instructions as to shaping, grinding and tempering of metal cutting tools. The "Drilling and Boring of Metal" is then considered with sundry illustrations and tables. "Screw Threads, Screw Cutting and Taper Turning" occupies several pages, including tables and illustrations. Maany other matters of a practical value to mechanicians, etc., are to be found in this little volume, "too numerous to mention."

The Diary, at the end of this book, consists of 26 pages with space for brief notes, for the week days of the year. The book is well worth the moderate price to those interested in mechanical engineering, shop work and the like.

Sewer Construction. By Henry N. Ogden, C. E., Professor of Sanitary Engineering, Cornell University. John Wiley & Sons, New York. 336 pp., 6 by 9 ins. 192 illustrations and many tables. Cloth. Price $3.00.

This book is an amplification of a course of lectures given to students of Civil Engineering specializing in sanitary engineering. It is an excellent work and worth the price asked. It has a most complete index and is good as a work of reference It follows the author's work on Sewer Design, so contains nothing but descriptive matter connected with actual sewer construction work.

There are twenty chapters, as follows: I. Terra-cotta Pipe. II. Teracotta Pipe (continued). III. Brick Sewers. IV. Concrete Sewers. V. Concrete and Brick Sewers. VI. Reinforced Concrete Sewers. VII. Manholes. VIII. Catch-Basins. IX. Siphons. X. Screens. XI. Stormwater Overflows and Regulators. XII. Bell Mouths. XIII. Foundations. XIV. Outfall Sewers. XV. House Connections. XVI. Surveying. XVII.

Trenching. XVIII. Estimates and Costs. XIX. Specifications and Contracts.

The text is clearly written and the illustrations are excellent. Such a book has been greatly needed by engineers engaged in sewer work and the arrangement reminds one of several excellent foreign works, not available particularly in this country because of differences in practice. As a treatise on the best American practice of today in sewer construction it can be commended.

The appearance of the book is in harmony with the works produced by the publishers, who have excellent taste in the selection of bindings and who employ binders that know how to bind a book. I. M.

TELEPHONE CONSTRUCTION METHODS AND COST. By Clarence Mayer. Cloth, 6 by 9 ins. 284 pp., including index. More than 100 illustrations and many tables. Price $3.00. Myron C. Clark Publishing Co., Chicago and New York. 1908.

The need for a work dealing with *costs* of telephone construction has long been felt; much more so than the need of a book on telephone construction methods. The fact, however, that it would be almost impossible to adequately treat the subject of costs without outlining the methods to which such costs apply is ample warrant for the inclusion of the somewhat detailed description of methods as found in the work under consideration.

Mr. Mayer's former employment as Cost Statistician of one of the very large telephone operating companies would seem to speak well for his ability to deal with this difficult and complex subject. It is also calculated to inspire confidence in the accuracy of the remarkably complete cost tables that are presented in his work.

Entirely aside from the quantitative value of the costs given, the work is valuable in its classification of cost items and in its methods and forms of cost accounting for all branches of outside construction work. It is safe to say that no such complete sets of cost figures have ever before been presented, and a cursory examination of some of these figures seems to indicate that they are reasonable and close to what would be expected in practice for similar classes of work. The subdivisions of the cost items involved in the carrying out of a piece of work might be criticized as being too minute, but it is better so than to have a less detailed classification, since combinations of items given by Mr. Mayer may readily be made in case persons following his methods of cost accounting desire a less detailed showing of results.

The value of the work would have apparently been enhanced and its completeness added to if it had been made to embrace the inside as well as the outside construction work. Central office buildings and equipments are not included, nor is any data given on the cost of telephones, substation wiring, etc. It is true that the costs of these branches of work are more readily determined than those of the outside construction work, but nevertheless some information concerning the cost of these items would be a great convenience and would round out the scope of the work.

The work as a whole is a very valuable addition to the literature of the telephone industry. K. B. M.

LIBRARY NOTES.

The Library Committee wishes to express thanks for donations to the library. Back numbers of periodicals are desirable for exchange and in completing valuable volumes for our files.

Since the issue of the JOURNAL for October, 1908, we have the pleasure to report the following additions to the library and gifts from donors named:

MISCELLANEOUS GIFTS.

City of New York. Board of Water Supply, "Data regarding Roudout Pressure Tunnel, and One-half of Bonticou Grade Tunnel, with drawings. Contract 12, being portions of Catskill Aqueduct. Also, Data regarding a portion of the Wallkill Division of the Catskill Aqueduct. Contract 15, with drawings. 4 Pams.

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Department of Auditor of State of Ohio, "Bureau of Inspection and Supervision of Public Offices. Comparative Statistics of Counties of Ohio, 1906". Pam.

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James F. Case, M. W. S. E., Manila, P. I., "Portland Cement Testing" by Beibling and Salinger. Pam.

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Bion J. Arnold, M. W. S. E., Chicago, "Electrification of the St. Clair Tunnel", by F. A. Sager. Pam.

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Engineering News Book Department, New York, "Smoley's Parallel Tables of Logarithms and Squares", 1908. Leather. "The Design of Highway Bridges", by M. S. Ketchum. Cloth.

Geological Survey of Ohio, Fourth Series, Bulletin No. 9, "Coal". Pam.

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"Special Report No. 1, Interstate Commerce Commission".

"Report of Department of Public Works, Chicago". 1907.

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"The Theory and Practice of Bridge Construction", by M. W. Davies, 1908. Cloth.

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John Brunner, M.W.S.E., Chicago—

"The Mississippi River from St. Louis to the Sea", by J. A. Okerson and C. W. Stewart. Cloth.

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A. P. Low, Director, Geological Survey of Canada, "Reports from Department of Mines". 5 Pams.

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"Bulletin No. 19, Zinc and Lead Deposits of the Upper Mississippi River", 1907. Pam.

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American Railway Master Mechanics' Association, "Proceedings", 1908.

GOVERNMENT PUBLICATIONS.

Experiment Stations—
Farmer's Bulletins Nos. 268, 269, 277.
"Industrial Alcohol."
"Tests of Internal Combustion Engines on Alcohol Fuel."

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Book Reviews